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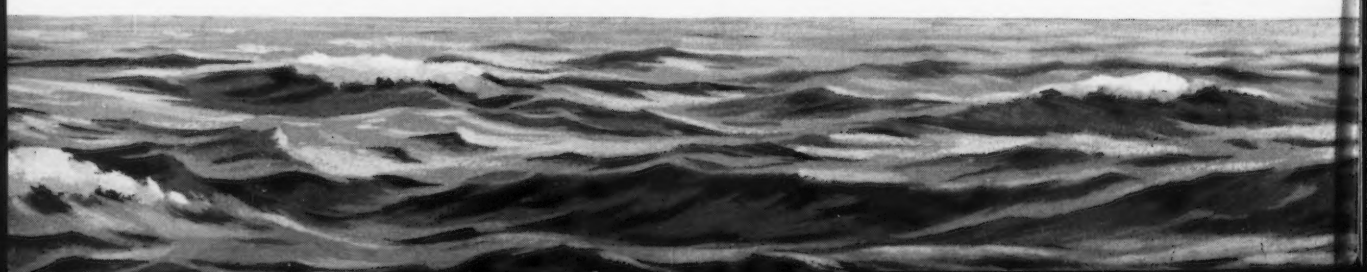

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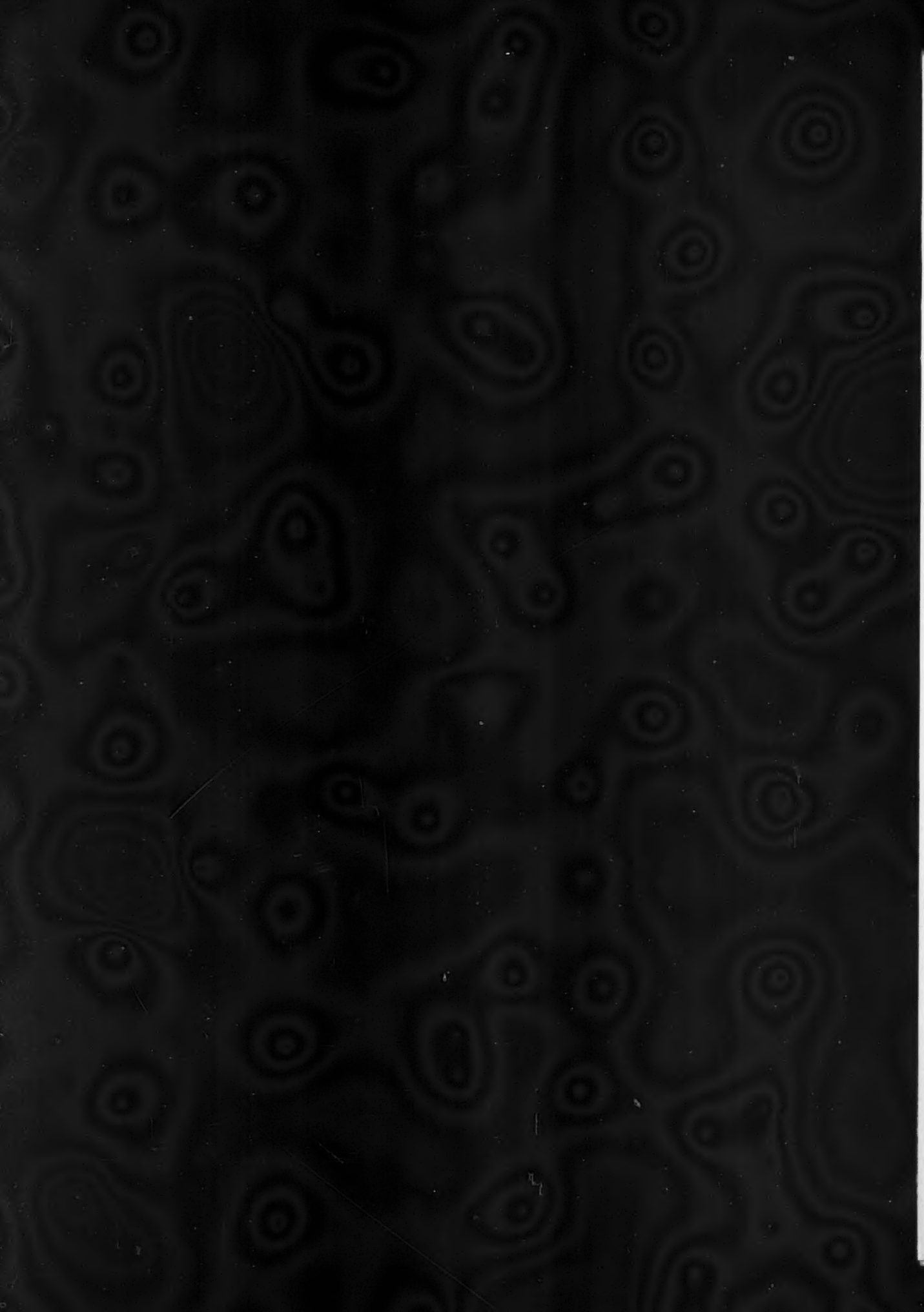

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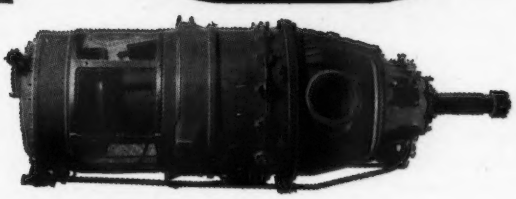

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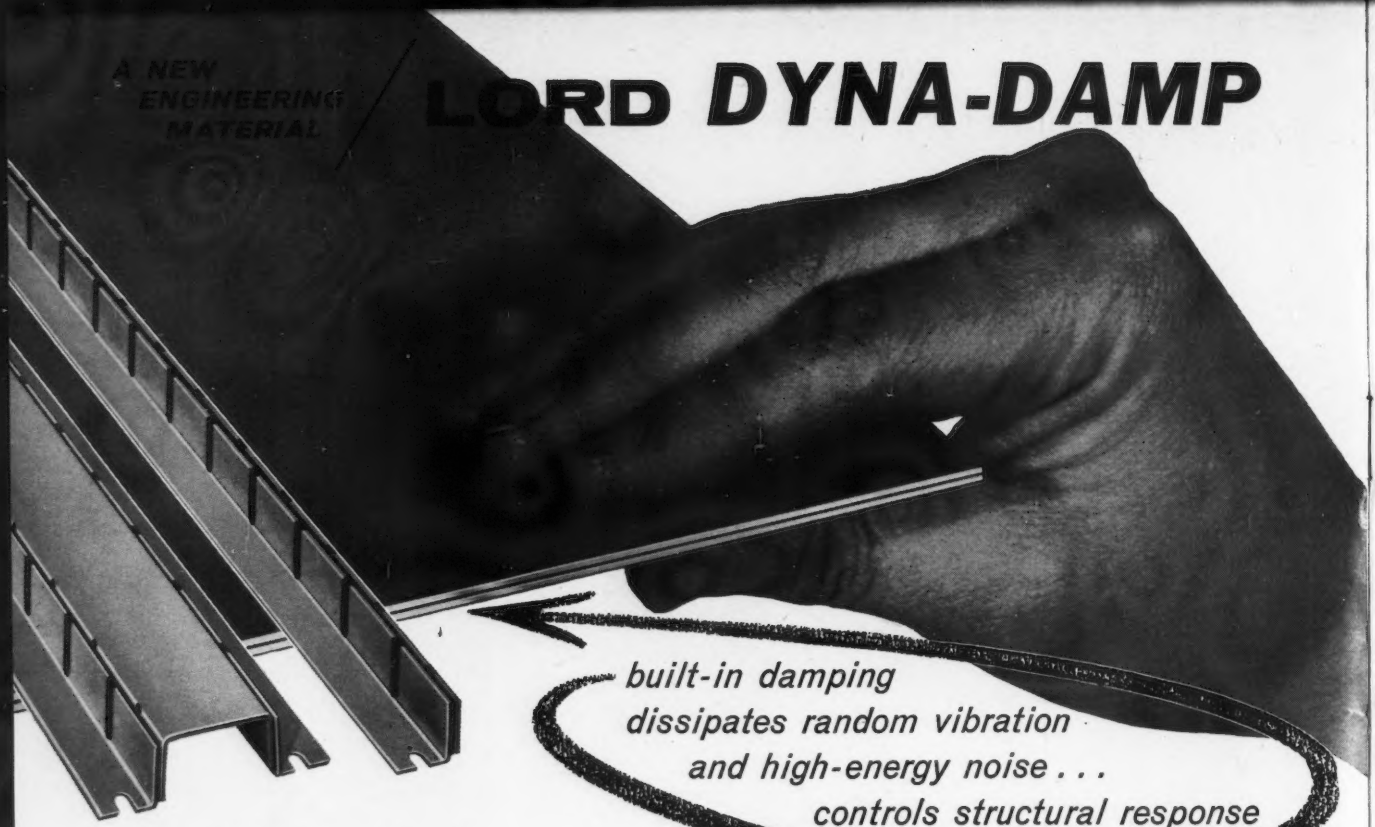

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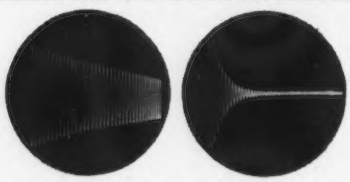

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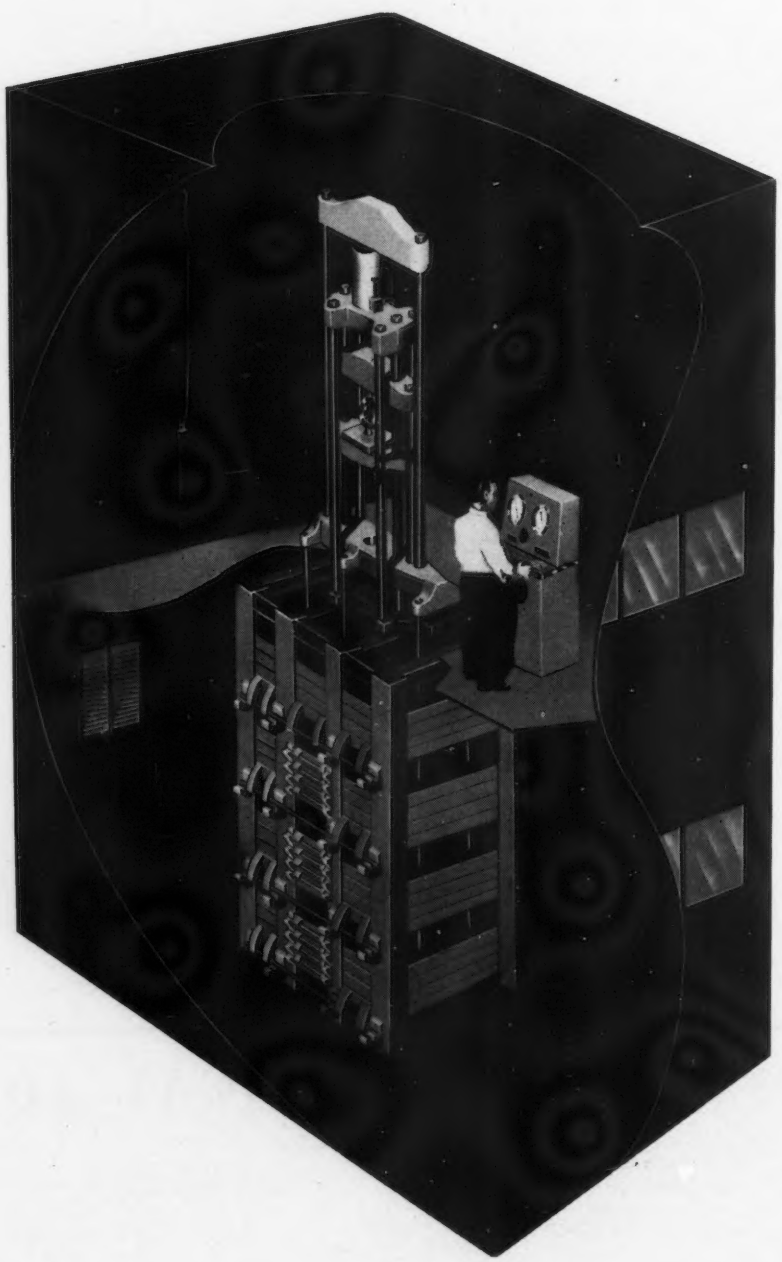
N.A.E. STANDARD FORCE MACHINE



An artist's sketch of the new 100,000 lb standard force machine which has been installed in the Structures Laboratory of the National Aeronautical Establishment in Ottawa.

EDITORIAL

THE PLACE OF RESEARCH AND DEVELOPMENT IN PRODUCTION SHARING

RESEARCH and development in the aeronautical industry in Canada occupies a position of top priority in the Canada-US defence production sharing program.

While the principle that Canada and the US should pool their economic resources for defence has existed for many years, the production sharing program is a relatively new element in the relations between the two countries and its immediate basis lies in the major defence policy decisions of 1959. These decisions made it perfectly clear that, because of the increasing complexity of modern weapons systems and the growing integration of Canadian-US measures for continental defence, it would be impractical for this country to undertake alone the development and production of its major defence systems. Having accepted this fact, the two governments established the production sharing program with the immediate object of increasing the participation of Canadian industry in the production and support of North American defence weapons and equipment.

I have reported to Parliament on progress achieved during 1959 and the first half of this year in the placing of US defence production contracts in Canada. I believe that the buyer-seller relationships which are being established will progressively produce more and more significant results in this area, as recognition of our industrial capability by US government and prime contractors becomes more broadly established.

It is not enough, however, merely to secure production orders. The government is determined to provide for the aeronautical industry opportunities within which it may by energetic and aggressive efforts retain and upgrade the significant level of scientific and technological ability which it had established during the past seven or eight years. During that period our aeronautical industry experienced phenomenal growth and since its main products were designed in Canada, research and development activity kept pace with the expanding industrial capacity. It is the aim of the government to provide opportunities for a retention of a comparable level of R & D activity in the new situation. In July 1959, therefore, the two governments agreed to pursue energetically the development sharing aspect of production sharing, and working procedures were quickly devised to identify for Canadian industry opportunities for participation in US defence R & D projects. For its own part the government, in 1959, appropriated funds to assist Canadian industry in the establishment in Canada of development projects aimed at providing new designs which will meet the combined military requirements in the two countries and which would place our industry in a favourable competitive position for follow-on production.

Our experience to date establishes three distinct sources for R & D work under the program. First, there is the Canadian original design which meets the US military requirement and this class is exemplified by such developments as the CL-44, the turbinized version of the Caribou aircraft and the 500 hp PT-6 turbine engine. Secondly, procedures have been established under which US military development projects may be brought into Canadian industry through funding by the Canadian government. Finally, there is the area of opportunity for Canadian firms to compete with US companies to secure US defence development contracts on the straight basis of price, quantity and delivery.

Of these, there is strong evidence that in the long run the most realistic opportunities lie in the area of the Canadian original design and in research and development in Canada which will produce a product technically

superior to anything being offered by US competitors within the time scale.

Recognizing that under present conditions corporate funds available for research and development are limited, my Department is continuously reviewing with the aircraft industry projects where the government may share with industry the cost of development up to the point where prototypes can be produced and sold in the North American defence market. For its part the aircraft industry must take the initiative in generating projects of this nature and it cannot be over-emphasized that a high degree of corporate initiative is essential if we are to capture a significant position in US defence development programs. An increasing number of Canadian firms have demonstrated clearly that technical competence coupled with aggressiveness can secure US defence orders involving R & D work of high caliber.

The CANADIAN AERONAUTICAL JOURNAL continuously provides evidence of Canadian technical competence in the aeronautical field and I am confident that this competence, exploited by a strong and continuous market research and sales effort, can ensure our retention of a significant R & D capability in the aircraft industry and produce the volume of follow-on production which is the basis of the joint program of the two governments.

THE HON. RAYMOND O'HURLEY
Minister of Defence Production

N.A.E. STANDARD FORCE MACHINE

A STANDARD force machine, in the range 2500 lb to 100,000 lb, has been installed in the Structures Laboratory of the National Aeronautical Establishment, Ottawa, and is available as a reference standard for the calibration of high precision scientific and industrial equipment.

A general view of the installation is shown in the artist's sketch of Figure 1. Although the supporting base is grouted into bedrock, the machine itself stands entirely above ground level, the control console and loading heads being some fifteen feet above the main laboratory floor. Two operators are required, one to manipulate the console controls and record observations on the test piece, the other to arrange weight selections from the storage rack beneath*. The whole unit is housed in a dust-controlled enclosure which is maintained at a pressure slightly above atmospheric, the circulating air and leakage replacement being drawn through three-micron filters.

The operating principles of the machine can be seen in the schematic diagram of Figure 2. An array of calibrated weights (1) is stored on a system of ladder bars (2) which transfer their load directly into the main supporting frame. Removal of appropriate ladder bars allows a preselected arrangement of weights (for example group (1A)) to rest on lifting pans attached to the lifting rods (3) so that the resulting load on the weighing beam (4) is reacted through either a compression test

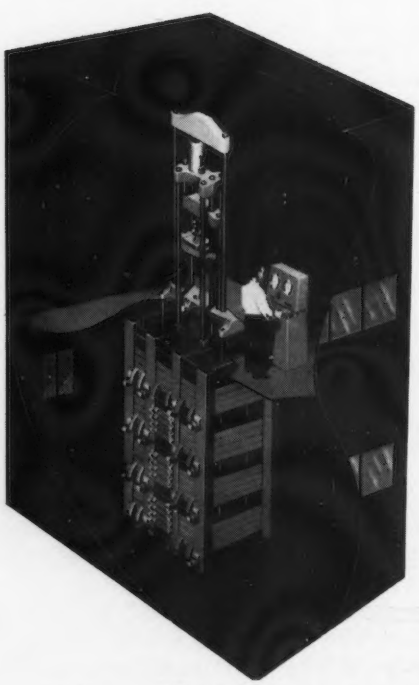


Figure 1
100,000 lb standard force machine

On being questioned about the second operator in Figure 1, the NAE advised us that he happened to be standing, out of sight, behind the machine, when the sketch was made! — Sec.

piece (5) or a tension test piece (6) to the frame (7) by way of the adjustable crosshead (8) and supporting columns (9).

It will be observed that the compression crosshead (10), the tension rods (11) and the lifting rods (3), together with the weighing beam (4), form part of the acting load at all times. This establishes the minimum load capacity of the machine. Removal of the ladder bars to transfer selected weights to the acting load is accomplished by raising all the weights clear of the ladder bars. This is done by means of the lifting ram (12), which raises the lifting crosshead (13) until the lifting collars (14) of the tension rods seat against the weighing beam to carry it and the entire complement of weights upwards. Excessive displacement of the hydraulic ram is prevented by an over-riding limit switch. When the system is lowered, those weights which are left unsupported on the ladder bars are carried directly by the weighing beam. A pressure gauge at the console serves to verify the nominal weight which is then being reacted through the test piece.

The machine will accommodate tension specimens from 1 ft 3 inches to 5 ft 3 inches long and compression specimens up to 3 ft 9 inches. Clearances allow for a width of 1 ft 7 inches and specimen deformation of 6 inches. Loading rates can be controlled from the console but, if a specimen should break or collapse under load, a pressure relief valve connected to the cylinder (15) serves as a shock absorber to retard the settling mass of weights.

The full capacity of 100,000 lb is obtained from forty-eight 2000 lb weights, three 500 lb weights, and a 2500 lb tare weight of the lifting and supporting components. Load values ranging from 2500 lb to 76,000 lb may be varied in 500 lb increments, and loads from 76,000 lb to 100,000 lb in 2000 lb increments. These loads can be quoted to an accuracy of 5 parts in 10^6 when calibrated corrections to the individual weights are applied, and to 18 parts in 10^6 when the nominal calibrated values of the weights are accepted as drawn in routine weighing. Individual weighings were maintained well within these limits by the design and construction of a high precision balance sensitive to unbalanced mass differentials of less than 1 part in 10^8, and by carefully

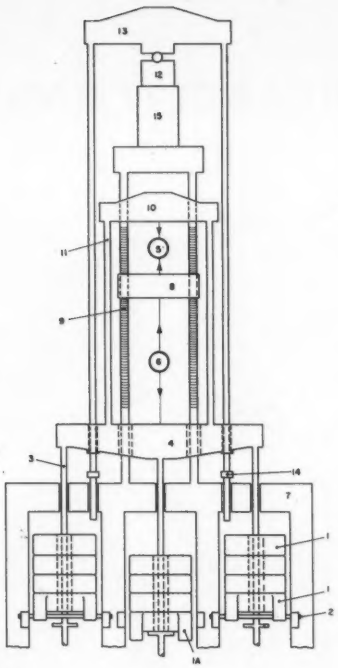


Figure 2
Schematic diagram

chosen weighing techniques. The final quoted accuracies are arrived at as the lower limits indicated by analysis of the experimental data to which is added an estimation of the effects of temperature, pressure and humidity on the buoyancy of the weights, the possible differential gravitational attraction between active and inactive masses, as well as the differential forces due to local magnetic field gradients.

The availability of this primary standard force is of great significance and will be welcomed by those organizations which, in the past, have had to send their force measuring references to such places as the National Bureau of Standards in Washington or the National Physical Laboratory at Teddington.

W. RUPERT TURNBULL LECTURER

Mr. A. E. Raymond

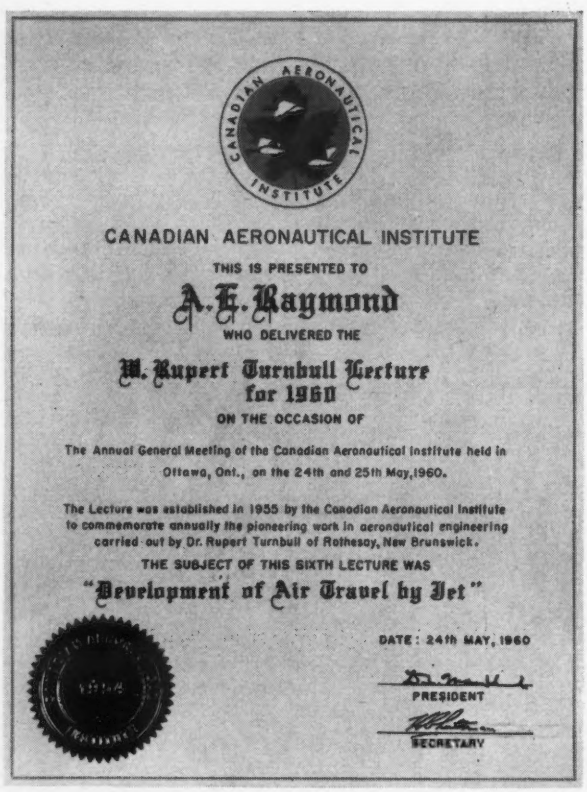
Mr. Raymond was born in Boston, Massachusetts, in 1899. He graduated from Harvard University in 1920 and was granted a Masters degree in Aeronautical Engineering by the Massachusetts Institute of Technology in 1921. He holds an honorary degree of Doctor of Engineering from the Polytechnic Institute of Brooklyn.

He started at the Douglas Aircraft Company in 1925 as a metal worker, the only position then available, but was soon transferred to engineering. He became Assistant Chief Engineer in 1927, Chief Engineer in 1934 and Vice-President in charge of engineering in 1939. In October 1958 he became Senior Vice-President, a position he held until his retirement this summer.

He has received many awards for his contributions to aircraft design and production and in 1950 was elected to the US National Academy of Sciences.

Mr. Raymond was President of the Institute of the Aeronautical Sciences in 1946 and was elected an Honorary Fellow in 1949.

Mr. A. E. Raymond, Vice-President, Engineering, Douglas Aircraft Company, Inc., was invited to deliver the Sixth W. Rupert Turnbull Lecture on the 24th May 1960 in Ottawa. Unfortunately he was prevented from doing so in person and his lecture was presented on his behalf by Mr. J. B. Edwards, Assistant to the Vice-President, Engineering. The lecture appears on the following pages.



CANADIAN AERONAUTICAL INSTITUTE

THIS IS PRESENTED TO

A. E. Raymond

WHO DELIVERED THE

W. Rupert Turnbull Lecture for 1960

ON THE OCCASION OF

The Annual General Meeting of the Canadian Aeronautical Institute held in Ottawa, Ont., on the 24th and 25th May, 1960.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS SIXTH LECTURE WAS

"Development of Air Travel by Jet"

DATE: 24th MAY, 1960

PRESIDENT

SECRETARY

A PHILOSOPHY OF JET TRANSPORT DESIGN†

by A. E. Raymond*

Douglas Aircraft Company, Inc.

I AM most appreciative of your kindness and courtesy in inviting me to represent Air Transportation in this 6th Turnbull Lecture. The year 1960, although it has seen many ups and downs in our industry, must be regarded as the year in which Air Transport came of age. I say this, not only in terms of today's demonstrated capability, but in terms of the tremendous potential which now becomes apparent.

The first half of this century has given us the education, the experimentation, the development and the understanding which must be preparatory to the fulfillment of promise. During this period, we have not only learned to fly – we have identified and learned to understand the principles of flight. The refinements in aerodynamics, the evolution of propulsion, the attack on structural fatigue, the advances in electronics, the development of navigation and air control concepts, the man-machine matching theory, these and many more technological achievements have made great strides. These gains, of course, have had to be coordinated with a realization of the dangers as well as the advantages of flight, and the elements of safety, reliability, comfort and economics which were so essential to the expansion and growth of air transport.

Dr. Turnbull, your distinguished colleague, is entitled to our gratitude and respect not because he was a pioneer in aviation, but because he possessed the quality found in all who have contributed greatly to achievements in every field. This quality is one of perceptive analysis and directed effort to solve fundamental problems. Without attempting to describe details of his activities which are well known to all of you, let me say simply this: his recognition that propulsion, airfoil efficiency, and stability and control must be examined and developed and that he dedicated his effort to such fundamentals, makes Rupert Turnbull one of the true founders of aviation as we know it today.

Strangely enough, although the refinement of propeller design was one of Turnbull's notable achievements, he has been quoted as recognizing that the airscrew was not the ideal means for aircraft propulsion, and that a better means must be found. By now, I am sure we all agree with this point of view, and my assertion that air transport has come of age in 1960 is based fundamentally on the change in total capability as we progress from propeller to jet.

†The W. Rupert Turnbull Lecture for 1960 was presented on behalf of Mr. Raymond by Mr. J. B. Edwards, Assistant to the Vice-President, Engineering, Douglas Aircraft Company, Inc., at the Annual General Meeting of the C.A.I. in Ottawa on the 24th May, 1960.

*Senior Vice-President — Engineering

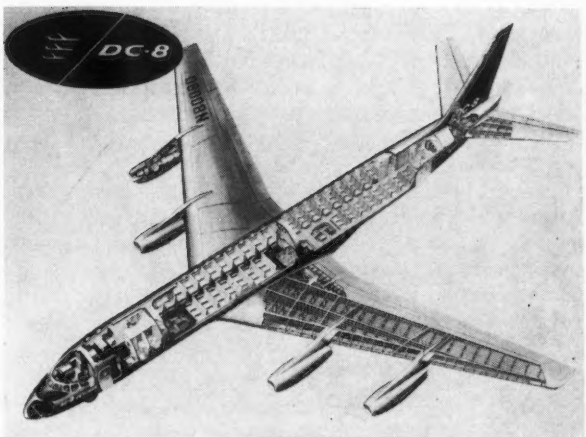


Figure 1
Cutaway view showing general layout

Air transport in Canada, in the trunk line sense, is the province of two great airlines – TCA and CPAL. The development of long range flying, which by now is the major method of passenger transportation between continents, was the natural path of these airlines, and the influence of the jet on their operations will be tremendous.

DESIGN PHILOSOPHY

We at Douglas feel honoured that our DC-8 has been selected by both of these airlines as their equipment for long range operations. Because of this selection, I feel I can talk about the DC-8, as an example of the maturity of air transport, without injecting commercialism into this meeting; furthermore, since you, as a group, represent the scientific aeronautical interest of Canada, I believe you should be acquainted with some of the design thinking and philosophy that characterize this airplane.

When one thinks of the millions of man hours which have gone into the design of the DC-8, and the scope of technical problems to which this effort was addressed, it is obvious that my discussion today must be based upon examples. By the use of various drawings and charts I hope to acquaint you with our thinking on the configuration and technical features of the aircraft; the response to operational and economic requirements of the operator; and the care devoted to the safety and comfort of the passengers and crew.

Figure 1, a cutaway view of the DC-8, will serve to give you a general idea of the total layout of the airplane.

I need only one picture for this purpose, since all DC-8's are identical in size and shape. The normal differences due to airline preference exist in cabin arrangements and choice of engines, and the gross weight variation from approximately 265,000 lb to 315,000 lb is accounted for largely by the quantity of fuel carried – there being some 35,000 lb more fuel in the intercontinental version than in those for domestic use.

Several important elements of the DC-8 may be brought out with the aid of this and the following figures; these may be classified in terms of design objective to indicate the scope of activity in such a program.

An example of *structural integrity* is illustrated by the wing design. With 3 spar, triple torque box construction, it is seen to be a continuous beam from tip to tip. The only joint is at the centerline, thus eliminating the sometimes troublesome structural connections conventionally found at the sides of the fuselage and at detachable outer wing panels.

As an aid to *service reliability* and *aerodynamic cleanliness*, most antennae of the DC-8 are of the flush variety and all are clean aerodynamically. This, plus simplified maintenance, is of great importance in high speed design and we are getting excellent service results from a truly advanced installation.

- FLIGHT SIMULATOR
- HYDRO-STATIC TEST
- SOUND SUPPRESSOR & THRUST REVERSER
- BLO-AWAY JET (AERODYNAMIC SCREEN)
- STATION ACTIVITIES SCHEDULE
- RUNWAY TURN CAPABILITY

Figure 2
Typical system studies

To provide *flexibility in airline operations*, the seats and bulkheads are mounted on tracks and can be rapidly rearranged for varying proportions of first class and tourist accommodations. As a further refinement in *passenger comfort* combined with *flexibility*, each seat contains the table, fresh air outlet, stewardess call button, reading light and pop-out oxygen masks. The connections for these conveniences are carried through an umbilical cord for each row of seats and are simply plugged in to a sidewall manifold when the seat has been positioned on the tracks.

The large triple-paned windows provide both *comfort* and *safety*. Their size and location allows a good view even from the aisle seats, and the combination of three panes, each of which is capable of taking several times the pressure load, not only is a guarantee against sabotage or carelessness, since the middle pane cannot be touched, but is equal in sound attenuation to the solid cabin walls.

Another *safety* element, based on historical experience and giving full appreciation to the catastrophic effects of a major explosive decompression at jet transport flight altitude, is the development of plug type doors and emergency exits. The DC-8 fuselage is pressurized throughout, including the under-floor cargo compartments, and every door and exit can only seal more securely as pressure is built up.

As a final item from this picture, I would mention that attractiveness to the passenger, and a long overdue

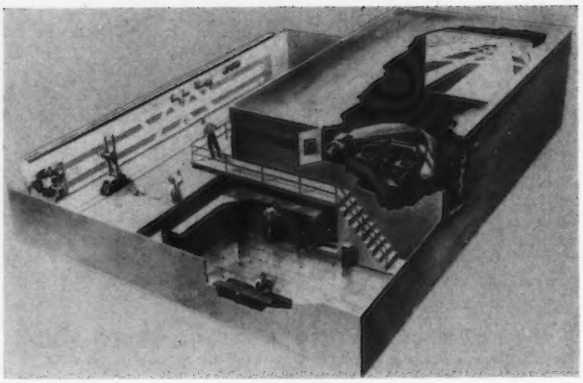


Figure 3
Flight simulator

modernization of transport aircraft, is accomplished by a flushing lavatory.

SYSTEM STUDIES

Figure 2 is intended to convey why designing a good commercial transport is not solely a matter of airplane technical design. There are listed here a few examples of the hundreds of studies carried on during the design of the DC-8 which have to do with regard for the passenger, the crew, the general public and the operator. With the next half dozen illustrations, I will enlarge a bit on each of these items.

Simulator training

Figure 3 portrays the installation at the Douglas DC-8 airline training facility of the special flight trainer built by Link to Douglas specifications. Our study of such a trainer began in 1956, and the trainer was built and in service prior to the first flight of the DC-8. This unique development and timing permitted the Douglas test pilots to be fully checked out on systems, emergency reactions, flight control forces and responses, and takeoff and landing procedures before ever flying the actual aircraft. An additional novel feature was developed by Douglas engineers and licensed to Link for visual approach and landing simulation. This device, called Telorama, uses a closed circuit television system, in which the screen is placed in front of the cockpit, and the camera, which responds in all three axes to the pilot's actuation of the aircraft controls, travels along a large scale map of any desired airport and runway system.

The safety and economic advantages of simulator training are well understood, and in the case of DC-8 airline pilot training, which we accomplish with each of

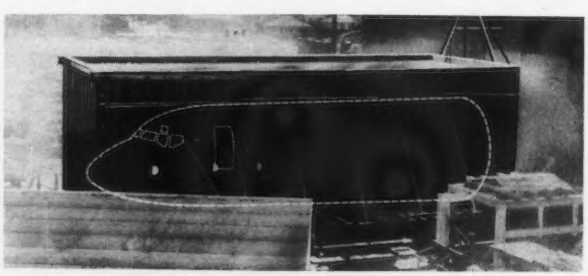


Figure 4
Hydro test tank
(Approx. 140,000 gal. tank)

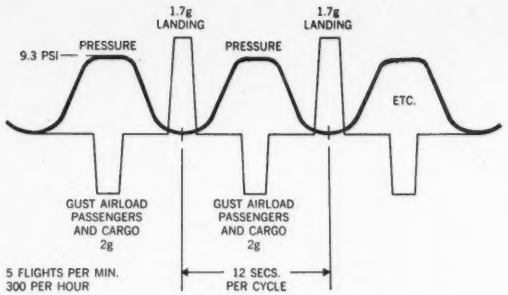


Figure 5
Underwater loading program

our customers, crew time for check out on the actual airplane averages 10 to 15 hours compared with twice this amount when simulator training is not used.

Structural test

Turning now from safety in pilotage to safety against structural fatigue and decompression, Figure 4 shows the hydrostatic test installation in which the DC-8 fuselage was subjected to the various stresses which are applied in actual operation. The location of the fuselage is indicated, and I should explain that all doors, windows, landing gear connections and wing connections were also examined by this test.

The schedule of loading is shown by Figure 5. In sequence, the fuselage is pressurized to 9.27 psi which is the sum of 8.77 psi (the pressure to provide a cabin altitude of 6,700 ft when flying at 40,000 ft), and 0.5 psi which is the additive effect of aerodynamic suction in cruise flight. While under this pressure, and with full payload simulated, the fuselage is subjected to a 2g gust loading. It is next brought down to sea level and a landing load of 1.7g is applied. Then comes the unloading of payload, and a new cycle is ready to be generated. With reference to the 1.7g landing load, I should explain that this intensity apparently happens in actual commercial practice only about once in every 50,000 landings. The normal landing which we experience as passengers varies from 1.06 to 1.1g depending on weather conditions and pilot skill.

An exaggerated diagram of the deflections of the fuselage under these various loads is shown in Figure 6. After our tests had completed 140,405 cycles they were arbitrarily stopped on the basis that our purpose had been accomplished. This amount of testing is equivalent to over 140,000 flights, which at an average of 3 hours per flight would be 420,000 hours of service, or well over a

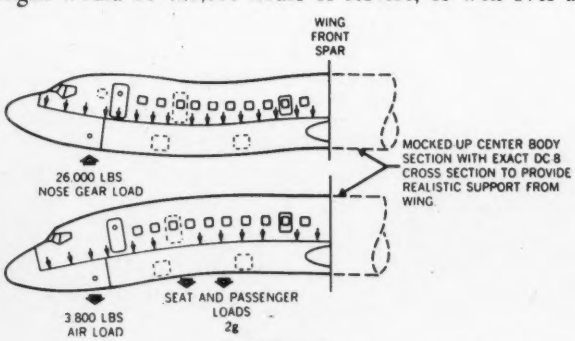

WING FRONT SPAR
MOCKED UP CENTER BODY SECTION WITH EXACT DC 8 CROSS SECTION TO PROVIDE REALISTIC SUPPORT FROM WING.
26,000 LBS NOSE GEAR LOAD
SEAT AND PASSENGER LOADS 2g
3,800 LBS AIR LOAD

Figure 6
Landing and flight loads

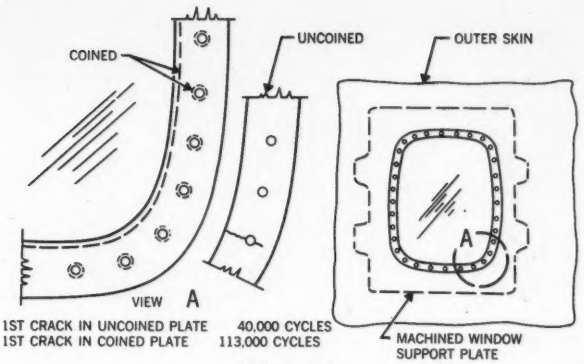


Figure 7
Coined window attach holes

hundred years under average operating conditions. As might be expected, several detail faults were discovered during these tests, usually in cracking of clips, brackets, etc. These, however, all became apparent in the first few thousand cycles, and after correction had over 100,000 cycles of proof. Each change found desirable during the test program was applied to all DC-8 production aircraft prior to delivery.

As a final item on this subject, and related to my previous remarks about the protection afforded by triple-paned windows, Figure 7 illustrates a further refinement in fatigue protection by coining of the periphery of attach holes and the plating itself to which the windows are attached. Quite obviously, the benefits of good window pane design would be wasted if the entire panel could blow out due to attaching structure fatigue. In order to verify the benefits of this technique, window installations in the test fuselage were made with and without coining. The uncoined installations developed cracks at some 40,000 cycles, and the coined installations showed no cracks until over 113,000 cycles. These later cracks were not repaired, and had shown no elongation at the time our tests were stopped.

Engines

In the development of jet installations for commercial applications, we found ourselves faced with several problems which had not needed to be explored during the preceding military jet operations.

Significant among these was the development of sound suppression and thrust reversal. Figure 8 shows a

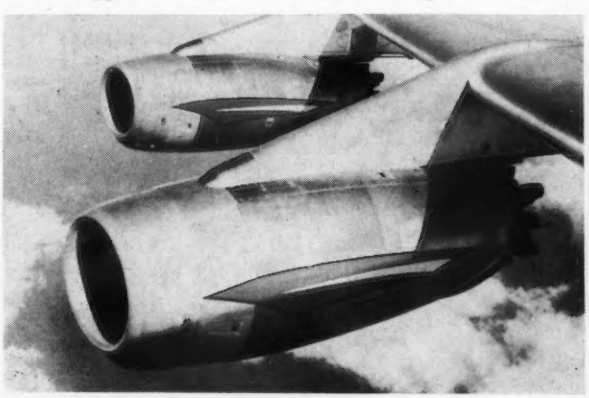


Figure 8
Sound suppressor

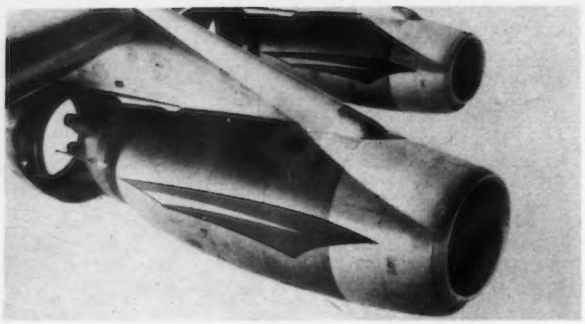


Figure 9
Reverser

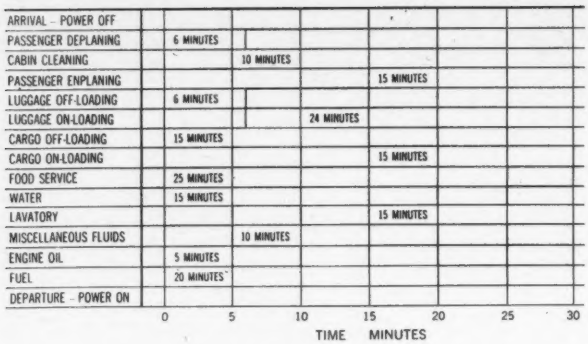


Figure 11
Station activities

flight view of this installation in the closed, or cruise, position – and Figure 9 shows the open position used at takeoff, at landing and as a flight brake during cruise or descent operation. I think something about the basic Douglas approach to design problems is illustrated by this example. Instead of considering the isolated functions involved, an effort was made to develop a functional, well integrated assembly, which would regain some of the takeoff thrust lost by exhaust noise suppression, produce the best possible muffling of the noise and, by the reverse thrust actuation, be useful not only in the landing roll but also as a flight brake. This combination of objectives was accomplished with a clean installation consisting of a daisy type suppressor at the engine nozzle, enclosed by an ejector ring containing the reverse clamshells which, when retracted, forms the aft engine cowling.

This development was a long, arduous, and costly thing, but the millions of dollars spent in engineering and testing pay off in improved operational economics, safety and public acceptance.

Another example of original thinking is shown by Figure 10. Since statistics told us that over 50% of jet engine damage in military service was caused by ingestion of objects drawn in from the ground during engine run up and taxi operations, it was obvious that the reliability and cost of maintenance of the DC-8 could be greatly helped by a solution to this problem. A basic idea, followed by nearly a year of exploration, plus service test on a number of military aircraft, proved that our so called "Blo-away" jet, or aerodynamic screen eliminates this problem completely with regard to pick up and ingestion of ground debris.

Handling

With the increase in cost and productivity of these jet aircraft over their predecessors, it becomes more and more important to minimize the time required for enroute stops or terminal turn arounds. Figure 11 is a time schedule for the various activities involved in a full scale terminal turn around. Obviously, each of the activities had to be studied, and the design of the aircraft elements optimized to permit the best efficiency. As examples, large passenger doors are provided both front and rear; service doors are provided opposite the passenger doors for buffet handling and other service activities; rapid cargo handling is provided by the installation of two large doors in each underfloor cargo compartment; underwing pressure refueling is used; and special servicing equipment has been designed to reduce the number of units required for the various air conditioning, engine starting and other functions.

LANDING GEAR

Another arrangement unique to the DC-8 is the landing gear. Figure 12 indicates the swivel action of the main gear which permits almost the same turning radius

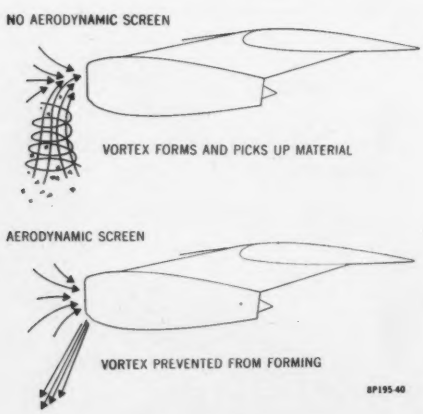


Figure 10
Aerodynamic screen

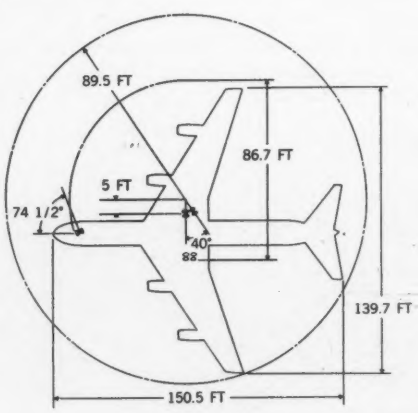


Figure 12
Turning radius

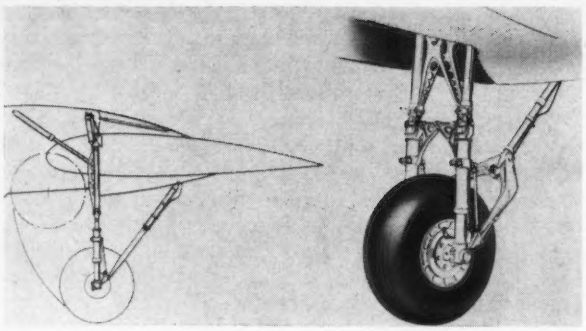


Figure 13
DC-3 landing gear

and protection against tire scrubbing which is normally accomplished by an axial, rather than bogie, type gear. Our design sequence in this case was that we first designed the main gear to have the four wheels on each side on a common axle. This was ideal for turning, braking, and retraction simplicity – but would have required greater beam strength in the runways, taxiways etc, which would mean more thickness of concrete. Changing to a bogie gear satisfied this problem, but only by designing the rear wheels of each bogie to swivel for sharp turns were we able to retain most of the other advantages.

The landing gear, of course, is an excellent example of the increasing mechanical and structural cost and complexity as transport aircraft have become larger and faster. I would like to illustrate this point by a brief review of the gear design of the DC-3, the DC-7C and the DC-8.

Figure 13 shows a diagram and general view of the DC-3 gear. This was a straightforward, single wheel, swing retraction gear with no doors or uplatches. It did not retract entirely into the nacelle, and some of you may remember that not only in the early Douglas test flying, but in service, very successful rolling landings were made with the gear in the up position. Usually the only effect on the airplane was to reduce the diameter of the propellers.

Figure 14 shows the increased problems exemplified by the DC-7C. Here are dual wheels, clean and complete

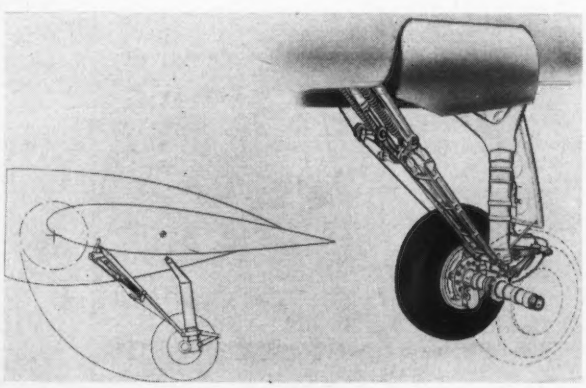


Figure 14
DC-7 landing gear

retraction with wheel well doors, a steerable nose wheel, up latches, and free fall provisions in case of hydraulic failure or malfunction.

Figure 15 shows the further increase in problems when we designed the DC-8. Now we have a twin-tandem bogie with swiveling rear wheels as discussed earlier; now we have a strong torque reaction on the bogie beam from brake application, which required hydraulic damping and control for porpoising and centering; now we have a gear which must rotate 90° while swinging sideways to the retracted position; now we have doors which must be closed while the gear is down as well as when it is up; and we have added to our design problems by a nose gear which not only has conventional steering, but has rudder pedal steering up to 10° of turn to improve the capabilities of the pilot in takeoff and landing operations. Perhaps it is not too surprising that the design of the DC-8 landing gear cost us as much as we spent to design the entire DC-3 airplane.

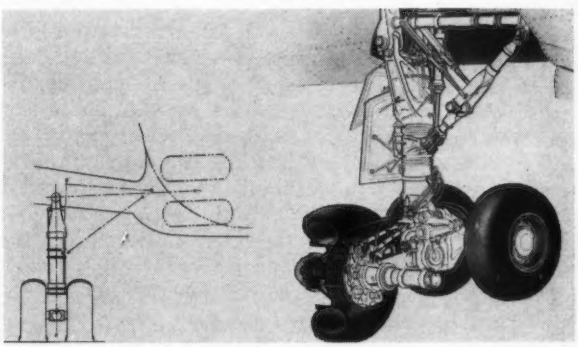


Figure 15
DC-8 landing gear

The following tabulation will give an idea numerically of the design problems in these various gears.

	DC-3	DC-7C	DC-8
Des. vert. load lb	53,000	201,000	444,000
Piston dia inches	3½	6¼	9½
Heat treat psi	125,000	190,000	260,000
No. of wheels	2	4	8
Tire pressure psi	45	125	170
Retract time sec	12	8	8
Lift off speed mph	97	148	200
Brake energy ft lb (million)	7	112	331

DC-8 CONFIGURATION

If I may turn now from the discussion of mechanical design to the sometimes more rarefied atmosphere of aerodynamic research and its applications, you may be interested in some further examples of unique development.

Wing

Figure 16, entitled "wing design criteria" provides a fairly inclusive view of some of the requirements and problems facing the commercial transport aerodynamicist, and the solutions reached in the case of the DC-8. This chart summarizes the main factors involved in wing design. Of the many aerodynamic decisions that must be made, the major ones are the selection of airfoil shape,

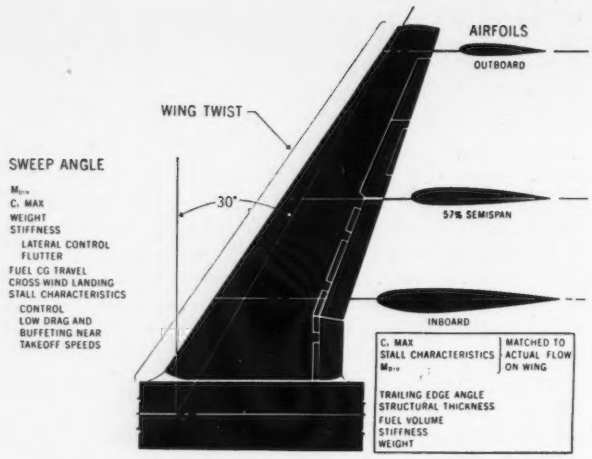


Figure 16
Wing design criteria

sweep angle and wing twist. Of course, the wing area and aspect ratio are also major parameters but these are selected in fairly conventional means by performance analyses. These performance studies compare the weight and drag characteristics of different aspect ratios. Wing area is usually selected to meet the landing and takeoff requirements. Thus, the main aerodynamic decisions are wing sweep, twist and airfoil shape.

In selecting the sweep angle we must consider the factors listed on the chart. Among these are M_{DIV}, which is increased by high sweep, and wing weight and stiffness, which are adversely affected by high sweep. Stiffness affects lateral control since, if the wing is not adequately stiff the most desirable means of lateral control, namely ailerons, cannot be used. Flutter, of course, is a very serious problem and wing stiffness helps to eliminate it under all expected flight conditions. The balance is affected by fuel center of gravity travel which is influenced by sweep because sweep angle determines the longitudinal dimension of the wing fuel tank. Crosswind landing is affected by sweep because high sweep angle makes the airplane very stable directionally and it is very difficult to build in adequate sideslip capability in such a design. Stall characteristics are affected by sweep because high sweep tends to cause the outer panels to stall first causing pitch up and adversely affecting lateral control. Furthermore, high sweep angle leads to leading edge separation at moderately high lift coefficients. This, in turn, causes increases of drag and buffeting at angles of attack approaching the stall. This is an important problem in landing and takeoff. In summary, we find that higher sweep angle is unfavourable in all stability, control and weight characteristics – but it leads to a higher M_{DIV}.

When we review the factors affecting airfoil selections we find many of the same characteristics are present. The airfoils are the major factors influencing the $C_{L_{max}}$. Stall characteristics are also affected since, if a swept wing has a tendency to stall on the outer part of the wing, this can be balanced by using airfoils of higher lift capability on the outer part of the wing. The airfoil determines the M_{DIV} to a large extent. Another factor that must be considered in airfoil design is the trailing edge angle, which must be kept low enough to maintain proper hinge moments and avoid control surface buzz at high speeds. The structural thickness affects the wing weight. The wing fuel volume is influenced by the airfoil shape as is the stiffness of the wing.

Now, a basic design concept of the DC-8 has been that it was to fly with the same sound stability and control characteristics that low speed airplanes possess. We could not permit problems such as pitch-up, tuck under, wing dropping, buffeting, stall and hazardous takeoff characteristics, that so many swept wing airplanes have shown. Therefore, it was our desire to develop excellent flight characteristics throughout the design by minimizing the sweep angle. At the same time, we could not afford to accept a reduction in M_{DIV}. The solution to this dilemma started with the discovery of a different family of airfoils. This family, the ancestor of the DC-8 airfoil, was actually a standard series known as the NACA modified four digit series. It was found to possess better high Mach number drag characteristics than any other type of airfoil. Intensive investigation of the reason for this airfoil's superiority led to the development of special Douglas airfoils. These airfoils carried the beneficial characteristics of the NACA modified four digit series to a greater degree to achieve even better high speed characteristics, and excellent high lift characteristics as well. This airfoil is sufficiently better than the NACA standard 6 series airfoils, in general use on high speed airplanes, to permit the use of a reduced sweep angle. Thus, the DC-8, with 30° of sweep, has a drag divergence Mach number of 0.84 which is as high as is usually obtained with 35° of sweep. This ability to meet the required speed with 30° swept wing gives us the advantage of being able to use aileron control which is much superior for low speed handling. It eliminates the double system often used in which one has to use ailerons for low speed and spoilers for high speed. It further gives us a relatively stiff wing, important from the standpoint of flutter, and greatly helps the crosswind landing characteristics.

Now, having selected the basic airfoil type, there still remains the problem of varying the airfoil across the span. Figure 17 gives an illustration of the nature of the problem. The dashed line is a typical span loading showing lift coefficient versus span position for a straight wing. The highest lift coefficient is obtained near the

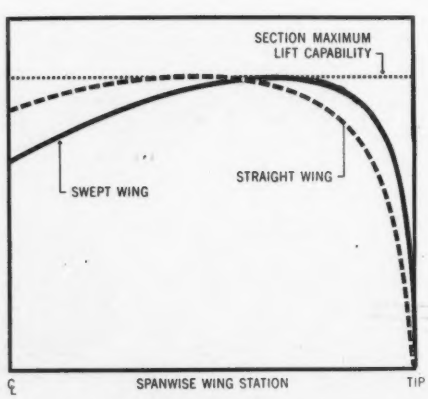


Figure 17
Typical spanwise lift distribution
(showing effect of wing sweep at the stall)

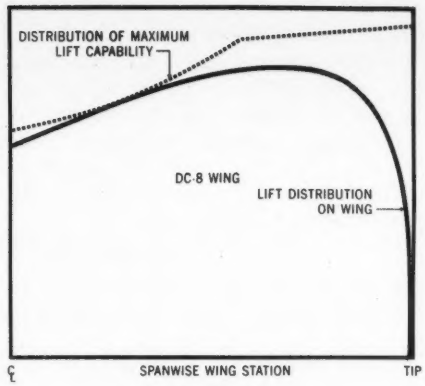


Figure 18
Spanwise lift distribution at the stall

middle of the semispan. The dotted line on the chart shows the section maximum lift capability. It can be seen that at the stall, that is, when the lift first meets maximum lift capability, the first part of the wing to stall is the middle of the semispan. The outer part of the wing where the ailerons are located remains well below the maximum lift capability. Therefore, the ailerons remain fully effective. In the case of a swept wing the comparable spanwise lift distribution is shown with a solid line. Here the maximum lift is first reached near the tips. Thus, the stall tends to occur first at the tips, causing loss of lateral control and unstable pitch-up.

In designing the DC-8 we have twisted the wing to minimize this tendency toward higher lift coefficients on the outer part of the wing, but there is a limit to how far we can go. Too much twist gives a less than optimum induced drag distribution for cruising flight. Having selected the twist in this manner, we then vary the maximum lift ability of the airfoil across the span as shown in Figure 18. By increasing the maximum lift capability over the outer part of the wing we have made the stall first occur inboard on the wing. Even though the lift coefficient is higher on the outer part when the stall first occurs, the outer part of the wing has a large margin of lift capability and the lateral control system remains fully effective. Now, in order to achieve this, the airfoil shape has to be varied from tip to root. We can go back to Figure 16 and see how this was done. We see that the airfoil on the inner part of the wing has a smaller nose radius of curvature than the airfoil on the outer part of the wing. This is associated with reduced maximum lift capability so that we have a higher lift capability on the outer panel.

Now, in addition to the maximum lift distribution, there is another very important design criterion to be considered. This criterion is required to avoid high speed pitch-up or tuck under. It is desirable for the wing to reach the critical Mach number at all points across the span at the same speed. That is, the M_{DIV} should be the same from the tip to the root of the wing. But there is a large fuselage interference effect at the root. This is the effect that has led to "coke bottled" fuselages using the so called "area rule" on our high speed fighter airplanes. Now in the case of a logistic aircraft, it is not practical to "coke bottle" the fuselage. Instead, we have varied the wing pressure distribution by varying the airfoil so that at the root of the wing the pressure distribution that results from fuselage interference and the special airfoil design is the pressure distribution that we normally have over the mid-semispan. This is the pressure distribution we wish to have in cruising flight. This special design of the root airfoil and the reduced nose radius gives the appearance of a negative camber on the root airfoil. Actually the pressure distribution, due to fuselage interference effect, has a strong positive camber so that the pressure distribution is essentially the same as that at the mid-semispan airfoil.

All other parts of the DC-8 have been designed with similar care and attention to basic principles. Figure 19 summarizes some of these. The flow across the swept wing is curved, tending to follow a direction perpendicular to the leading edge, and then curving back to the freestream direction. To minimize pylon-wing interference, we have actually cambered the pylons to follow the natural flow of the streamline on the swept wing.

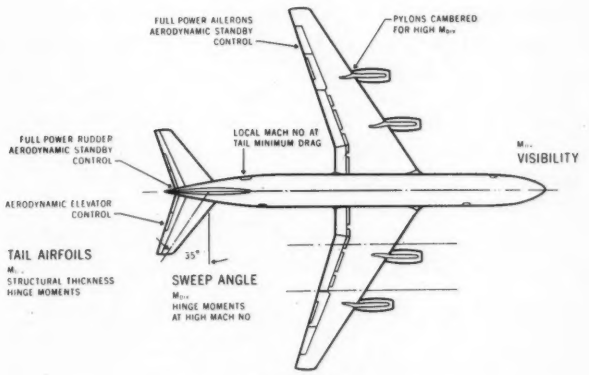

FULL POWER AILERONS AERODYNAMIC STANDBY CONTROL
PYLONS CAMBERED FOR HIGH M_{DIV}
FULL POWER RUDDER AERODYNAMIC STANDBY CONTROL
LOCAL MACH NO. AT TAIL MINIMUM DRAG
M_{DIV} VISIBILITY
AERODYNAMIC ELEVATOR CONTROL
TAIL AIRFOILS
M_{DIV} STRUCTURAL THICKNESS HINGE MOMENTS
35°
SWEEP ANGLE
M_{DIV} HINGE MOMENTS AT HIGH MACH NO

Figure 19
Component design criteria

Fuselage

The nose of the fuselage has been very carefully designed to minimize local velocities and achieve a high drag divergence Mach number consistent with the requirements for good visibility from the cockpit.

Very gradual lines of the fuselage aft end assures minimum drag. The tail end of the fuselage has been designed so that the curved part of the fuselage is placed well ahead of the tail surfaces. The tail surface itself is subjected to an airstream Mach number that is not only *not* higher than freestream but is actually lower. In addition, the horizontal and vertical tail are displaced from each other to eliminate interference.

Tailplane

The tail surfaces are designed to give excellent control characteristics at the highest dive Mach number of the airplane. Some of the factors involved in tail design are very similar to those involved in the wing design. These include airfoil thickness, airfoil shape and sweep angle. But having designed the wing, the decisions are somewhat easier. Since the same excellent airfoils are available for use on the tail, we need merely achieve a higher degree of sweep and a lesser thickness to assure good tail characteristics up to Mach number beyond the range of interest for the DC-8. The sweep angle is increased

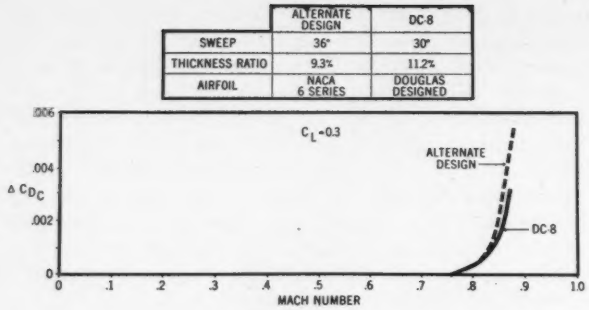


Figure 20
Compressibility drag rise
(wing-fuselage wind tunnel tests)

by 5° to 35° and the tail surface thickness is reduced below that of the wing to about 9%.

The elevators are manually controlled with aerodynamic boost tabs. Trim is achieved by a powered adjustable stabilizer.

The rudder has a full power control with an aerodynamic tab standby system. The system is so designed that a power failure automatically, and without any action on the part of the pilot, makes the manual system effective. The manual system is an aerodynamic boost tab system similar to that on the Douglas DC-6 and -7 airplanes.

Use of power on the rudder is required only to give greatest crosswind landing capability. As was mentioned earlier, swept wing airplanes are very stable directionally and resist yawing into the wind for crosswind landing. To achieve excellent crosswind landing characteristics, the moderate sweep was used as mentioned before, and in addition a full power rudder which can be deflected to 30° was used. This large rudder deflection angle would not be possible without power boost. Furthermore, the elimination of the lift loss due to the control tab, made possible by the use of power, further increases the crosswind landing ability.

Ailerons

The lateral control system uses fully powered ailerons with a manual aerodynamic standby system. The aileron is built in two pieces, connected by a torque link. The inner part of the aileron is powered, and is operated by the controls. At low Mach numbers, below 0.4 to 0.5, the outer aileron which is driven by the link from the inner aileron deflects with the inner aileron. We have, in effect, a large one piece control surface. At high equivalent airspeeds the loads on the outer ailerons cause the torque link to deflect, allowing the outer aileron to trail to lesser angles than the inner aileron. Thus, at high speeds where aeroelastic effects would cause the outer aileron to reduce the over-all roll control, the outer panel is automatically rendered ineffective. The roll control is maintained at a high level primarily with use of the inner surfaces alone. This system gives excellent control both at low speeds, even deep into the stall, and throughout the speed range up to the maximum demonstrated dive Mach number of the airplane. Over the normally used speed range of the airplane the roll rates are about twice those of previous logistic airplanes.

Flaps

Spoilers are shown ahead of the flap. These spoilers are used primarily to decrease the lift of the wing during the stopping runs and to increase the aerodynamic drag. The outer portion is also activated differentially when the flaps are in landing position and the ailerons deflected more than 8°. This is an additional aid in crosswind landings. The flap itself is a Douglas double slotted flap of advanced design.

General

Now, the question can be asked, have we achieved our goals in this design? First, I would like to show, in Figure 20, a high Mach number drag comparison of the DC-8 and an alternate design as obtained in wind tunnel tests. The alternate design is actually an A3D wing with 36° of sweep, 9.3% thickness and a standard NACA series airfoil. The DC-8 wing has 30° of sweep and 11.2% thickness, much less sweep and greater thickness. The data show that the high Mach number drag characteristics of these two airplanes are about the same. Actually the DC-8 data are slightly better than those of the more highly swept, thinner wing. These data show the effectiveness of the special airfoils in permitting equal M_{DIV} with all the advantages of lesser sweepback.

Figure 21 shows the high Mach number (0.85) wind tunnel pitching moments for a conventional large military swept wing design and for the DC-8. It is seen that for the conventional design an unstable break occurs in the moment curve at rather low lift coefficients. In flight test the moments were slightly improved, as is typical of flight test compared with wind tunnel, but the unstable break still exists. Use of vortex generators in flight considerably helps the situation, but some marked decrease of stability is still shown. The DC-8 demonstrates an almost linear moment curve, a result of designing for uniform M_{DIV} across the wing span.

Summarizing, I would like to emphasize that the DC-8 design is a fully rational aerodynamic system, in which every component has been designed not only for its own characteristic but for its relation to other parts of the airplane. I can fairly say that we have achieved a machine with transonic cruising speeds, which retains handling and stability and control characteristics quite like those of conventional straight wing airplanes.

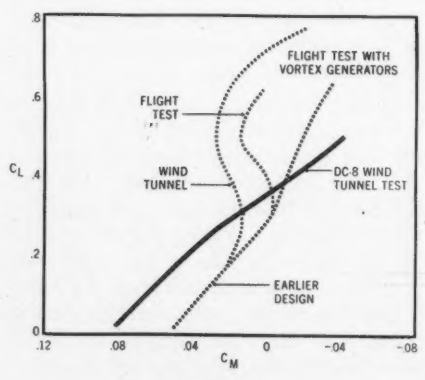


Figure 21
Longitudinal stability

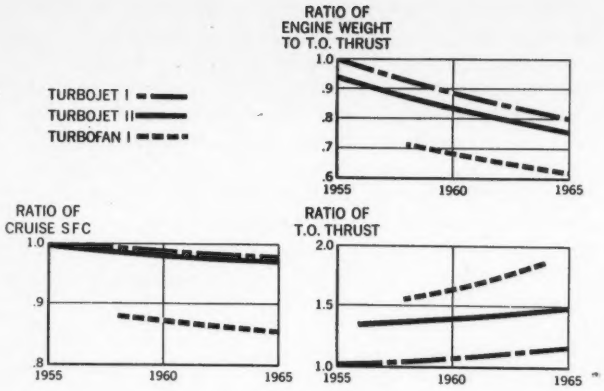


Figure 22
Engine growth

CONCLUSION

Up to this point, my discussion has been largely confined to what we may call the static aspects of transport aircraft design and philosophy. Certainly, the efforts to provide a maximum of safety, and economy, and comfort, and the passenger appeal which leads to operator prestige and profit are fundamental and do not change year to year or generation to generation. However, our technical horizons are constantly expanding and the dynamic quality which is thus imposed on the accomplishment of these ends creates a pattern of change which lives with the design from beginning to end.

Many of the technical advances which displace parts of the original design are relatively minor but tremendously important to the continuing success of a design type. Examples might be new and improved fire warning systems, a more accurate altimeter, a trustworthy fuel quantity measurement, a non-flammable hydraulic fluid – the list is as long as the components of the operational aircraft.

The element of change, however, which both directly and indirectly has the greatest influence on the growth and development of any given aircraft design is the powerplant. Recalling past history for just a moment, in order to present a complete example of such growth, let us look at the DC-4, -6, -7 series whose production ended in 1958 with the inception of the DC-8. This series, with no variation in geometry except increasing fuselage length and tail size, started its service life with engines of 1450 takeoff hp and a gross weight of 62,000 lb. The final version with the same wing geometry came some 10 years later, during which time the engine power had increased to 3250 hp and the gross weight had grown to 126,000 lb. During this period of growth, speed had increased from 250 to 350 mph, payload from 11,000 lb to 17,000 lb and the range with full payload from 1800 to 2700 miles. Even at this stage, the basic airframe was not over-extended, and deliveries were started in 1956 of the DC-7C. This aircraft answered the requirement for a long range intercontinental transport with high speed and good payload characteristics. The same basic wing was increased in span by the addition of five feet of straight section at each side of the fuselage. The fuselage was lengthened another 40 inches, and the result was the highly successful Seven Seas, with a takeoff weight of 143,000 lb, a payload of 17,000 lb, and a range with full payload of 3500 miles. No better example could be found of the amazing growth potential of a good airframe as engine development permits.

The DC-8, which is really just starting out in life, has already been subjected to such rapid developments in the powerplant field that there are five basic models of this type despite the fact that all DC-8's are the same physical size. The DC-8-10 represents our original concept, powered with Pratt & Whitney JT3 jet engines which were the commercial counterpart of the extensively developed and proven military J57. In Figure 22, this engine is non-dimensionally indicated by the curves marked turbojet I. Before the design of this airplane was completed, and well before first flight, turbojet II became available, and established our -20 and -30 intercontinental models. Starting at 275,000 lb takeoff weight, the intercontinental progressively climbed to 287,500 lb, 300,000 lb, and to 310,000 lb as the ratings were increased on turbojet II. The -40 airplane, powered by Rolls-Royce Conway, and selected by both TCA and CPAL, has experienced similar growth patterns. Although rated about the same as turbojet II in this figure, the Conway, being a bypass rather than pure jet engine, tends to lean toward the efficiency and power gains shown by turbofan I, which is now being installed in a test DC-8. Because of its improved characteristics, the turbofan is already under order as a replacement for the pure jet in existing aircraft, and is planned in most of the later production of the DC-8 as the -50 model.

Figure 23 shows very clearly and simply the influence of engine improvements on a given design type aircraft. Greater power, greater fuel economy, and lighter weight are the goals of engine improvement. Alone, or in combination as is usually the case, these improvements lead to an expansion of the payload/range diagram of the airplane. Where range is fixed, as in transcontinental operations, the gains may be applied to increase payload – and thus profit – or to reduce field length, which increases operational flexibility and helps the community noise problem.

Where field length is fixed, as in the case of the major terminals for intercontinental operations, a greater weight may be lifted from the same field. This greater weight

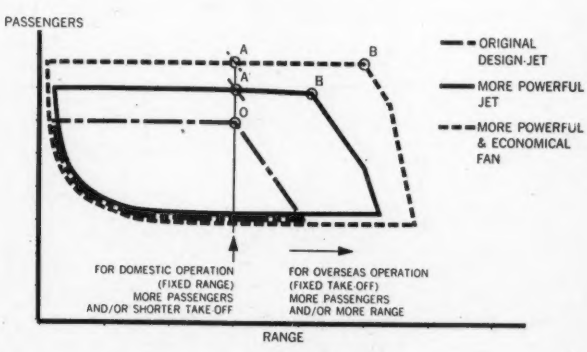


Figure 23
Qualitative effect of engine improvements on design exploitation

may be in payload, to increase profit, or in range to permit the establishment of new route segments previously unattainable. In either case, the net result, providing the basic design has been established with the foresight to accommodate such growth, is a continually improving profit and service potential for the industry, and a protection against early obsolescence.

In closing this review of the design principles and objectives of a transport aircraft, let me be quick to admit that not every objective is attained at the first attempt. Even the most extensive and carefully planned test programs fail to indicate problems which develop as the result of service experience in actual operation. The truly important considerations are that the basic design be completely honest in its conception, so that there is a solid foundation on which to make detail improvements, and that technical advance be recognized and encouraged as a never ending process.

McCURDY AWARD

The McCurdy Award will be presented at the Annual General Meeting, which will be held on the 25th and 26th May, 1961.

It is the premier award of the Institute and is presented annually

For outstanding achievement in the art, science and engineering relating to aeronautics.

The recipient shall be a person who, while a resident of Canada during recent years, has made a significant personal contribution in any field of endeavour, including, but not limited to, engineering, science, manufacturing, aircraft operations or management.

NOMINATIONS ARE INVITED

Each nomination should include

(a) The name and affiliation of the nominee,
(b) A citation of the particular achievement for which the nomination is being put forward,
(c) Confirmation that the nominee was a resident of Canada at the time of the achievement, and
(d) The name of the nominator.

The nominee need not be a member of the C.A.I.

Nominations should be in the hands of the Secretary not later than the 31st October, on which date they will be handed over to the Senior Awards Committee.

BRIEF EXPERIMENTS ON A FLAPPED AEROFOIL HAVING A CUSPED CAVITY AND A BLOWING JET AT THE CUSP†

by A. D. Wood*

National Aeronautical Establishment

SUMMARY

Experiments on a simple flapped aerofoil incorporating a cusped cavity and having a blowing jet at the cusp show that it is possible to produce a flow regime in which the cavity is occupied by a stable trapped vortex. With the aerofoil immersed in a quasi-two-dimensional finite stream, greater rotation of the resultant force vector was obtained with a flap of this type than with a flap having no cavity. The results indicate that the combination of a blowing jet and a trapped vortex may be used to advantage in enabling an external flow to overcome an adverse pressure gradient.

INTRODUCTION

Among the methods proposed for providing aircraft with the ability to hover or to operate from very confined areas is that in which the propulsive stream from the propellers is re-directed in order to produce a large vertical thrust component. This can be done by employing flaps having a sufficiently large chord. The more effective designs are segmented in the chordwise direction and employ auxiliary devices, such as slots, to improve the efficiency of the turning process[1]. Flow control, using blowing or suction, is also applicable and has been utilized in some of the laboratory experiments[2].

Investigations of this kind have been in progress for several years at the National Aeronautical Establishment. A number of these investigations, carried out in 1957 and 1958, involved a flapped aerofoil of somewhat unusual design. This aerofoil was of a shape designed for convenience of manufacture and was in no way representative of optimum design. The aerofoil was, in fact, derived from an ellipse, a large portion of which was cut away to provide a cusped cavity. A flap was installed on the lower side of this cavity and a slot for a blowing jet was provided in the region of the cusp.

It has been shown in Reference 3 that a cusped cavity may be employed effectively in other applications, notably in the case of a diffuser where the expansion may be accomplished within a shorter length by incorporating a cavity in the design of the walls. In such cases a stable flow condition may be achieved in which the flow adheres to the walls of the diffuser while enclosing a standing vortex within the cavity. By suitable design of the profile of the cavity and the walls, the vortex may be automatically stable. Alternatively, stability of the vortex may be achieved by applying suction within the cavity. A system of this kind has also been applied to an aerofoil and in Reference 4 some experiments are described in which tests were made on an aerofoil having a cusped cavity in which a stable trapped vortex was induced by applying suction near the trailing edge.

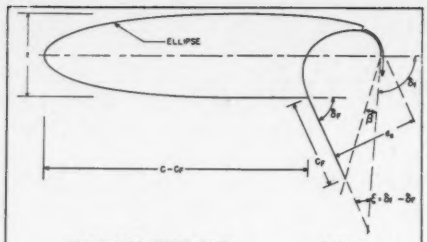
The success obtained in applying a cusped cavity to the design of a short length diffuser and achieving a stable trapped vortex configuration without the application of suction, suggests that the cavity is more effective than a continuously curved boundary in enabling a flow to negotiate without separation a region of strong adverse pressure gradient. A severe adverse pressure gradient is also characteristic of the condition occurring near the hinge line of a flapped aerofoil used, for example, in deflecting a propeller slipstream. The possible advantage to be gained by incorporating a cusped cavity in such an aerofoil configuration is therefore of interest. The circumstances are more severe, however, than those of the diffuser, particularly when very large deflection angles (70° or more) are required. For this reason, and to avoid unacceptably long flap chords, it is necessary in addition to consider the use of flow control by blowing or suction.

In the present instance it was decided to investigate the possibility of combining flow control by blowing with a flap configuration incorporating a cavity. The purpose of the work was to determine whether a rudimentary system of this kind could be made to work and whether any advantage over a more conventional plain flap configuration in obtaining very large deflection angles could be discerned which would warrant a more thorough investigation.

LIST OF SYMBOLS

F	Resultant force on aerofoil, lb
T	Thrust developed by incident airstream, lb
q	Dynamic pressure of incident airstream, lb/sq ft
S	Wing area of model, sq ft
C_μ	Momentum coefficient = $\dfrac{\text{rate of change of momentum of jet, lb}}{qS}$

†This paper is based on NAE Laboratory Report No. LR-269.
*Head, Flight Research Section



INSTALLED SPAN BETWEEN WALLS 3·875 IN
MAJOR AXIS OF BASIC ELLIPSE 6·00 IN
MINOR AXIS OF BASIC ELLIPSE t = 1·40 IN
NOMINAL BLOWING SLOT WIDTH 0·02 IN
AEROFOIL CHORD TO FLAP HINGE C-Cp = 4·50 IN
FLAP CHORD Cp = 1·50 IN
NOMINAL AEROFOIL CHORD C = 6·00 IN
SLIPSTREAM WIDTH D = 8·00 IN
AEROFOIL INCIDENCE 0 DEG.

Cp/C = 0·25, Cp/D = 0·188

CONFIG	δf°	δf°	dg IN	β°	dg/Cp	ζδf°-δf°
A	68	107	1·43	0 (Cavity Closed	0·95	39
B	68	107	1·43	0	0·95	39
C	68	101	1·43	6	0·95	33
D	68	95	1·43	12	0·95	27
E	90	118·5	1·20	0	0·80	28·5
F	90	113·5	1·20	5	0·80	23·5
G	90	111	1·20	7·5	0·80	21
H	90	108	1·20	10·5	0·80	18

Figure 1
Geometrical characteristics of models

APPARATUS AND TECHNIQUES

The aerofoil profile used for these experiments is shown in Figure 1. The shape was obtained by modifying an ellipse in the manner indicated by attaching a sheet metal flap to the lower surface, by building a blowing slot into the upper surface and by installing a thin sheet metal flap immediately under the blowing slot to serve as a means for controlling the direction of the blowing jet. The geometrical characteristics of various configurations tested are given in Figure 1. The model was constructed of brass sheet and provided with an inlet for blowing air at one end. The whole interior of the model served as a plenum chamber.

The apparatus for the aerofoil tests is shown in Figure 2. A two-dimensional arrangement was chosen, the model being installed between circular end plates mounted flush with the two transparent end walls. The incident air stream (a two-dimensional representation of a propeller slipstream) was obtained using the two stream boundary walls shown in the diagram. The aerofoil model was supported from beneath by a two-component strain-gauge balance of a type used previously for half-model tests. A small clearance gap was provided between the end plates and the walls, in order to ensure absence of restraints. The air supply from the compressor and tank passed through a venturi and was led to the model from above. A length of flexible rubber hose was employed in the section immediately above the model in order to avoid restraints from this source. The balance design was such that the model could be set at any angle of attack, but in the tests described here the angle of attack was always zero. In this apparatus it was possible to simulate ground effects by installing a ground plane in the desired position below the model. The end plates, end walls and ground plane were all made of transparent material to facilitate the use of flow visualization techniques. Pressure measurements across the incident stream, in the flow downstream and near to the aerofoil, were made by supporting single probes or rakes between the end walls.

Continuous records of balance readings were obtained using commercial pen recorders. Venturi and other pressures were measured using liquid manometers and recorded at the frequency required by means of still photographs. The flow was visualized using tufts, small vanes and by applying a chalk and kerosene mixture to the lower end wall. In using the last technique it was necessary to seal the gap between the end plate and the end wall.

In general, the procedure used was to fully open the tap from the air tank with the compressor running. Under these circumstances, the pressure fell away slowly from its initial value and a continuous record of the two force components was obtained. The corresponding manometer readings were recorded by a series of photographs. To obtain results at the lower blowing pressures it was necessary to shut off the compressor. A balance check calibration using weights was carried out before and after each run.

RESULTS AND DISCUSSION

The force measurements obtained for the eight model configurations of Figure 1 are presented in Figures 3 to 7. All forces are made non-dimensional by dividing by the thrust T of the incident stream. Results were obtained as a function of the momentum coefficient C_μ. The results are presented for the entire C_μ range available from the compressed air system. The variation of the resultant force vector F/T and the angle of rotation θ of the resultant force vector with C_μ are shown on the right hand side of each figure. The value of the momentum coefficient corresponding to each point on the vectorial presentation on the left hand side of the figure may be obtained by reading across to the right hand side at the same value of F/T. The relationship between the magnitude and the angular rotation of the resultant force vector is shown in the lower left corner of each diagram.

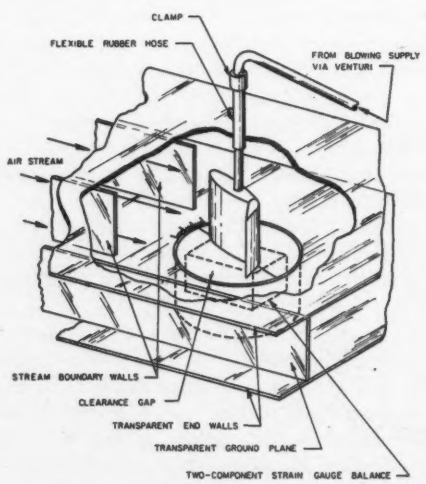


Figure 2
Sketch of apparatus for static two-dimensional stream deflection experiments

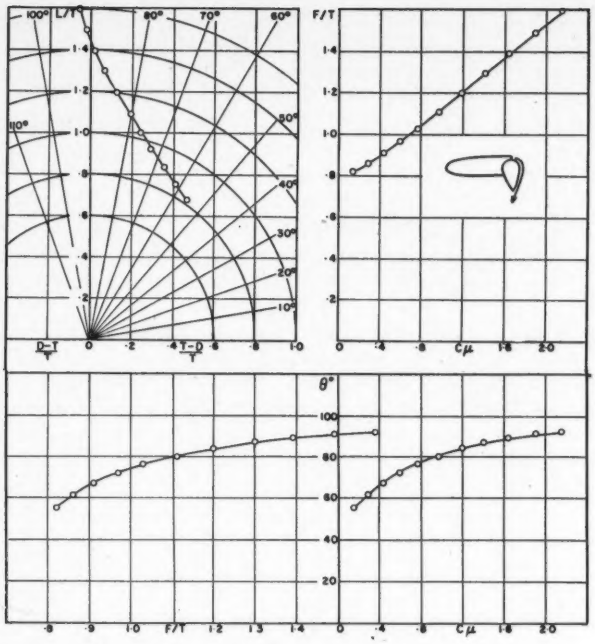


Figure 3

Typical results for aerofoil with blowing over plain, flat-sided flap without cavity ($\beta = 0°$)
$C_F/C = 0.25$, $\delta_F = 68°$

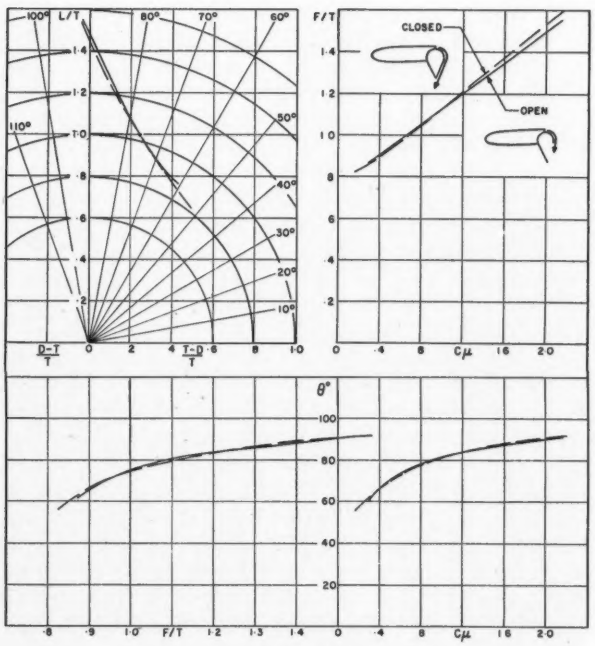


Figure 4

Effect of closing cavity in the case where $\beta = 0°$ (flat-sided flap)
$C_F/C = 0.25$, $\delta_F = 68°$

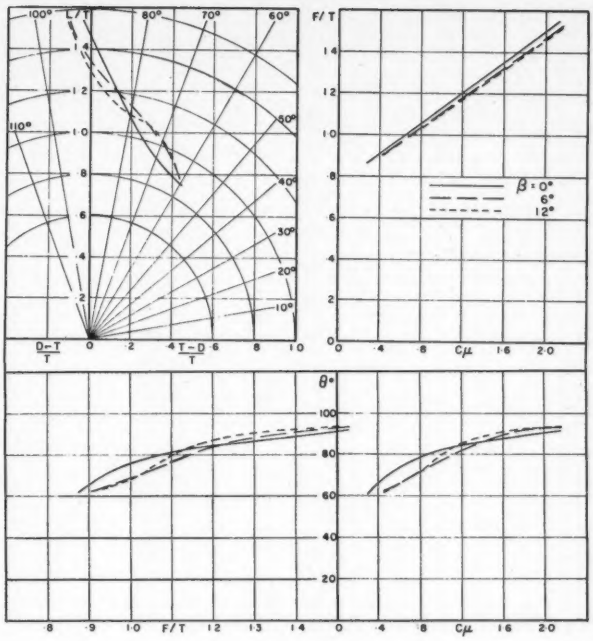


Figure 5

Effect of varying angle β for plain flap with cavity
$C_F/C = 0.25$, $\delta_F = 68°$

Typical results for the model with the cavity closed to represent a plain flap are shown in Figure 3. It will be seen from these results that the basic aerofoil and flap shape chosen provides only a moderately effective turning device at the small values of C_μ (less than 0.2) normally associated with blowing for boundary layer control. At the higher values of C_μ obtainable, the forces and turning angle continue to rise smoothly. At the upper end of the range the characteristics of the blowing jet correspond more closely with those normally associated with circulation control.

Figure 4 shows the results of Figure 3 compared with those obtained when the flat upper surface of the flap was removed. Very little difference was observed between the results obtained for the two cases.

Figure 5 shows the results obtained for the aerofoil with cavity when the small control flap under the blowing jet was adjusted to alter the direction of the blowing jet. The angle β, determining the position of the control flap, is defined in Figure 1. From Figure 5 it will be seen that as the angle β is increased from zero the characteristic curves obtained show a marked change of form. The resultant force vector as a function of C_μ is not greatly affected by variations of β but there is a strong effect on the angle of rotation θ. Referring to the curves of θ versus C_μ it is evident that for a positive value of β the angle of rotation is reduced at low values of C_μ but increases above that obtained for $\beta = 0$ at the higher values of C_μ. There appears to be a critical value of C_μ marking the transition between these two regimes. This critical value of C_μ is lower at the higher value of β.

A more marked example of this phenomenon occurred when the flap angle δ_F was increased from 68°

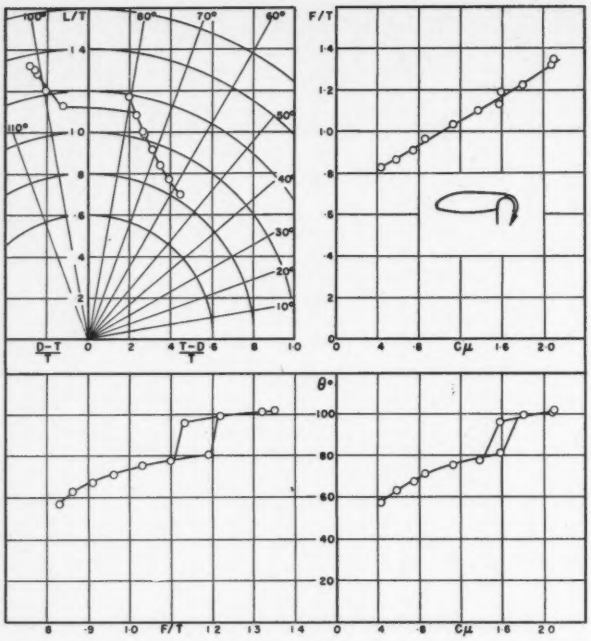


Figure 6

Typical results for aerofoil with blowing over plain flap with cavity and positive β (10.5°)
$C_F/C = 0.25$, $\delta_F = 90°$

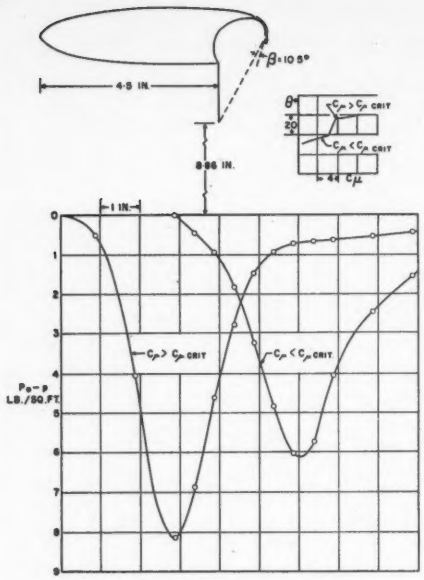


Figure 8

Downstream total head profiles
$C_F/C = 0.25$, $\delta_F = 90°$, $\beta = 10.5°$

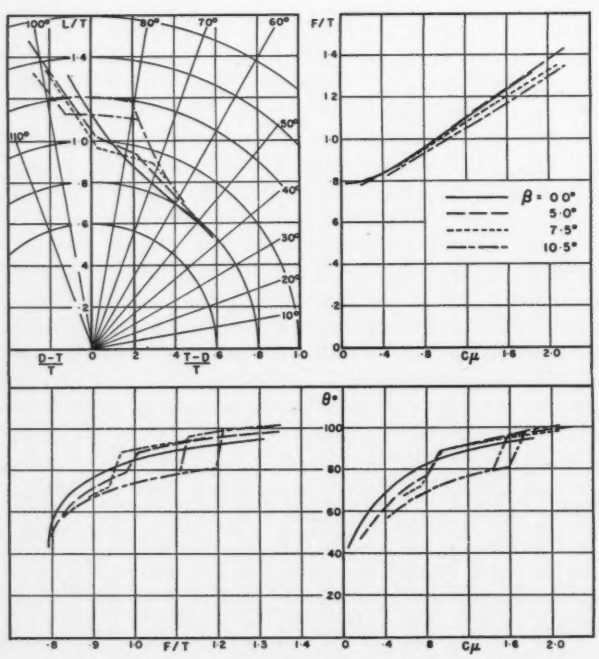


Figure 7

Effect of varying angle β for plain flap with cavity
$C_F/C = 0.25$, $\delta_F = 90°$

to 90°. The results obtained for this configuration when $\beta = 10.5°$ are shown in Figure 6. A sharp step in the curve for θ versus C_μ occurs in this case, the change in angle of rotation amounting to more than 15°. Some variation in the value of C_μ at which this step occurred was found during successive runs and this variation is shown in Figure 6.

The effect of varying the angle β from 0° to 10.5° for this configuration is shown in Figure 7. Again the values of θ obtained when β is positive for higher values of the momentum coefficient C_μ are higher than those obtained when $\beta = 0$, while the curves for positive values of β fall below that for $\beta = 0$ at the lower values of C_μ. The position of the critical momentum coefficient varies less systematically with β than was the case for configurations compared in Figure 5 and there is a contrary trend at the higher values of β. This inconsistency in the variation of $C_{\mu\,crit.}$ with β, together with the observed difficulty in obtaining precisely repeatable results near the point of transition, suggests that the value of $C_{\mu\,crit.}$ may be highly sensitive to secondary factors such as very small changes in the profile of the control flap or the spanwise uniformity of the flow on individual runs.

The predominant characteristic of a change of regime occurring at some critical value of C_μ for positive values of β is borne out by tests at both values of the flap angle δ_F. In the cases described, the potential advantage to be gained by operating at values of C_μ about $C_{\mu\,crit.}$ amounts to about 5° improvement to the rotation angle θ. At values of C_μ below $C_{\mu\,crit.}$, there is a large reduction in the angle of rotation to a value well below that obtained when $\beta = 0$ with the cavity open or closed.

Figure 8 shows typical total head profiles obtained mid-way between the end walls using a rake mounted downstream from the model. The two profiles shown were obtained at values of C_μ respectively below and

above critical value. Comparing these two profiles, the significant features are the marked shift in the position of the total pressure peak and the narrowing of both the high velocity and lower velocity regions of the stream when $C_\mu > C_{\mu\ crit.}$ The incident airstream has a mean dynamic pressure of 2.57 lb/sq ft and is practically uniform over its entire 8 inch width, with the exception of a region having a sharp gradient near the edges. The appearance of the downstream total head profiles therefore suggests that considerable entrainment of the incident stream by the blowing jet has taken place, particularly in the case where $C_\mu > C_{\mu\ crit.}$

The interpretation of downstream total head profiles needs some care since the local direction of flow in the streams is far from uniform and there may be some spanwise variations, particularly near the walls. Small vanes attached to the rake were used in positioning the rake and to indicate regions in which large inclinations occurred in the flow. Flow visualization using a chalk and kerosene mixture on the lower end wall was also useful for this purpose and a typical photograph obtained using this technique with a ground plane installed is shown in Figure 9. No large differences in the downstream flow angles indicated by the vanes and by the wall patterns were observed. Figure 9 indicates the entrainment by the jet of flow passing over the upper surface of the aerofoil. Also noticeable in this figure is the flow passing the trailing edge of the flap from above. This indicates that the jet, which leaves the control flap at a positive value of β, curves in such a way as to pass adjacent to the flap trailing edge. Under such circumstances a free streamline, dividing the jet from the lower surface flow, must emanate from a stagnation point at the trailing edge of the flap. The probable location of this streamline is apparent in the photograph. Its location at the flap trailing edge when $C_\mu > C_{\mu\ crit.}$ was confirmed by the use of a probe with a wool tuft. When $C_\mu < C_{\mu\ crit.}$ a thick turbulent wake was observed downstream of the cavity.

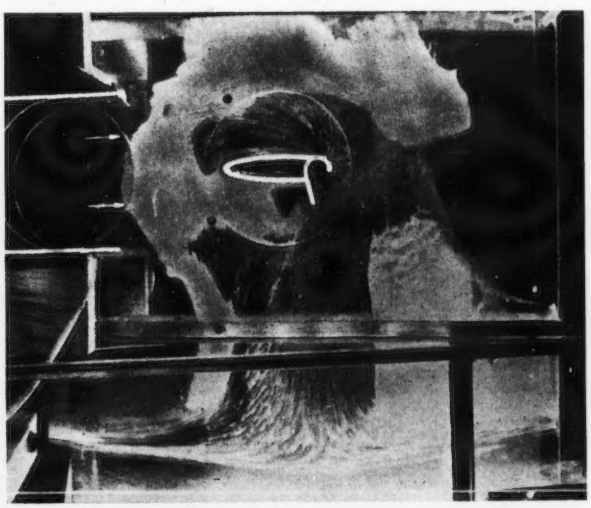


Figure 9
Typical flow pattern obtained using chalk and kerosene mixture on lower transparent wall ground plane installed
$C_F/C = 0.25$, $\delta_F = 80°$, $\beta \approx 10°$, $C_\mu > C_{\mu\ crit.}$

The over-all force measurements described provide evidence of a marked change in flow regime at $C_{\mu\ crit.}$ but reveal nothing explicit about the flow within the cavity. From observation of the flow it appears that when $C_\mu > C_{\mu\ crit.}$ the cavity is closed by a further stagnation streamline forming a lower boundary to the jet and joining the trailing edges of the control and main flaps. When $C_\mu < C_{\mu\ crit.}$ this streamline breaks away at the main flap trailing edge leaving a region of turbulence downstream of the cavity and adjacent to the lower edge of the jet. The appropriate total head profile in Figure 8 indicates a region of total head loss forward of the jet and extensive mixing between the two. These features are absent from the profile for $C_\mu > C_{\mu\ crit.}$

When the cavity is closed by a stagnation streamline a situation resembling the cavity flows of References 3 and 4 prevails. The presence of the jet introduces a considerable complication in evolving a corresponding theoretical treatment and a serious attempt at this has not been made. Nevertheless, with the assumption that the flow is truly two-dimensional, some conclusions may be drawn by analogy. It is reasonable to suppose, for example, that in the absence of viscous effects a similar external flow will result if the stagnation streamline enclosing the cavity is replaced by a solid surface of the same curved shape. The curvature of the stagnation streamline must be conserved, therefore, by a lowering of the pressure within the cavity and this requires the presence of a vortex since no other mechanism for obtaining the necessary pressure reduction is being supplied. In fact, the assumption of a purely two-dimensional regime is questionable since the span of the model is not large and effects resulting from the presence of the boundary layer on the walls at each end of the model are to be expected. A few pressure measurements made within the cavity, however, together with flow observations provided some direct confirmation of the existence of a vortex, although the extent of its resemblance to a two-dimensional vortex was not determined.

It will be obvious from the sketch of the aerofoil in Figure 1 that the greatest part of the angle turned through by the jet was accomplished by "Coanda effect" while passing over the control flap. The radius of curvature of this flap was relatively small and very low pressures were induced on its upper surface. The remainder of the turning resulted from the influence of the cavity. From observation and from the force measurements of Figures 4, 5 and 7, it appears that the curved stagnation streamline enclosing the cavity automatically ensured a greater angle of rotation of both the jet and the flow with it than would be expected by some arbitrary choice of flap contour such as a flat surface.

To a degree, therefore, the stagnation streamline provides a flexible boundary which accommodates itself to a shape favourable in preventing flow breakdown in the presence of an adverse pressure gradient. The purpose accomplished is thus directly comparable with that of the cusped diffuser in the wind tunnel. The means, however, differs by the inclusion of the blowing jet which serves both to create and to stabilize the vortex while acting as the intermediary in ensuring attachment and rotation of the surrounding flow.

As already noted, the model used was of rudimentary design. The flap chord was short and the corner to be negotiated by the flow extremely sharp. Under these circumstances high effectiveness as a turning device is not to be expected and it is not surprising that an interesting flow regime only appeared when C_μ reached a high value. There is no evident reason, however, why a flow of the same type should not appear at much lower values of C_μ on a more carefully designed model. The flap chord could well be increased and the over-all curvature with flap deflected made less sharp by incorporating, for example, a forward slotted segment to achieve the greatest possible rotation of the flow before the application of blowing, somewhat in the manner of Reference 2. The cavity is then a device which may lead to an improvement in the efficacy of an already well-designed blowing system. When it is recalled that rotation of the propeller thrust vector through an angle exceeding 70° is difficult to achieve by conventional means including blowing[2], the possibility of a further increment of even 5° is worth consideration.

Little progress in the direction of optimum cavity design for blowing applications can be expected without some theoretical formulation. As a first approximation an infinitely thin jet with constant velocity could be assumed. Whereas in the flow over a cusped cavity without a jet there is no pressure difference across the streamline separating the flow in the cavity from the external flow, in the case with a jet it would be necessary to assume a pressure difference across the jet directly related to the jet curvature and therefore to the curvature of the stagnation streamline. This assumption might be useful in examining cavity shape and the flow within the cavity. To obtain any indication of the ability of the jet and the external flow to remain attached, however, it would be necessary to take into account entrainment of the surrounding flow.

In a real fluid it seems probable that the difference in viscous effects at the inner boundary of the jet when passing over a cavity or over a solid surface having the same shape as the stagnation streamline will cause a difference in the ability of the flow to remain attached. In the latter case the inner edge of the jet will be subject to boundary layer growth while in the case of flow over a cavity there is no similar decay in velocity near the inner edge of the jet. Thus, while the jet supplies energy to the vortex, it preserves at its inner edge a velocity profile less susceptible to flow breakdown. So long as the flow remains attached at the flap trailing edge, which presumably depends upon the maintenance of a favourable velocity profile within the jet, the cavity may be regarded as a region of controlled separation and reattachment.

In a manner similar to that suggested in Reference 3 for flows including a vortex and a sink, the combination of a blowing jet and a standing vortex provides, then, a further method of influencing an external flow by generating a local region of controlled separation bounded by an appropriately shaped stagnation streamline. Both methods may be considered for application to flow problems in which it is necessary to make use of power in overcoming an adverse pressure gradient.

CONCLUSION

Experiments in quasi-two-dimensional flow on a flapped aerofoil incorporating a cusped cavity and having a blowing jet at the cusp have shown that it is possible to produce a flow regime in which the cavity is occupied by a standing vortex. With the simple model used in these experiments, flow of this type only appeared for large values of the momentum coefficient C_μ. At values of C_μ above the critical value the resultant force vector obtained with the model in a stream of finite width, representing the slipstream of a propeller, was rotated through a larger angle than for the case of the same flapped aerofoil with blowing but without the cavity. At values of C_μ below the critical value the effect of the cavity was adverse.

Since the model had many arbitrary features, more careful design would be expected to lead to considerably greater effectiveness with a stable trapped vortex appearing at much lower values of the momentum coefficient. A theoretical basis should be sought in order to allow more systematic experimentation.

The results obtained indicate that the combination of a blowing jet and a trapped vortex may be used to influence an external flow in a manner which is favourable in overcoming an adverse pressure gradient.

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ENGINEERS AND MANAGEMENT†

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Canadair Limited

INTRODUCTION

THE tremendous expansion of technology over the past decade or two has caused many changes in the industrial scene. Among these changes has been the increase in the number, size and degree of specialization of engineering departments and the resulting very great increase in the number of engineers employed by industry to do technical engineering work.

This condition has created or emphasized problems both from the point of view of management and of the individual engineer employee. These problems have encouraged extensive studies in the academic world as well as in the business and professional associations, and some students of management feel that one of the greatest problems currently facing industry is the proper management of the professional employee[1]. Although this discussion will be confined to the engineer-management situation, much of it is applicable to the professional employee generally.

Because of the importance and general interest in this subject, it was felt that discussion among members of the Institute would be appropriate. The objective of this paper is to promote such discussion and to encourage individual thought on the engineer-management relationship. It is not the intention to examine specific organizational arrangements and management methods relating to the accomplishment of engineering work, but rather to indicate in a more general way some of the situations and conditions which constitute the fundamental problem and to suggest some means of moving towards its resolution.

IS THERE A PROBLEM?

In case there is doubt that a problem exists, a few examples of the kinds of attitudes we run into from time to time should illustrate the point:

(a) *In managers*

(1) Disappointment at the performance of a highly rated professional employee after promotion to a supervisory or management position.

(2) A feeling that a project is being "over engineered" or that the technical people are making a meal out of a small problem.

(3) Complaints of lack of judgment or impracticality on the part of engineers.

(b) *In engineers*

(1) A feeling of being underemployed, that their technical contribution is being limited or rejected.

(2) Frustration with decisions that seem or are contrary to the best technical approach.

(3) Impatience with or indifference to such distractions as budgets, schedules and operating regulations.

(4) A feeling that their status as professionals is not adequately recognized.

The above examples are random and are not represented as being universal, but I am sure we have all run into one or more of them often enough to accept them as typical.

To understand why these attitudes may arise, it will be worth while to review for a moment, separately, the mechanism of management and the basis of professionalism.

MANAGEMENT

Management means many different things to different people, and in text books on the subject can be found whole chapters devoted to the definition of the term. For the purpose of this paper I would like to suggest the following definition:

> "Management is the function of combining the factors of production to produce an economic gain on a timely and continuing basis."

While this definition can readily be expanded and improved upon, it emphasizes the four important features of management that determine the characteristics of managers:

(1) Management is an active rather than a passive function.

(2) Economic gain is the primary objective.

(3) Time is always an important consideration.

(4) Management must seek to perpetuate the enterprise.

Just as a corporation is a legal entity, so a "management" is a functional entity with a distinct personality or characteristics. In some quarters it is popular to sum this up in the expression "corporate image" but more generally the nature of a management is associated with the word "policy". The dictionary defines policy as an adopted course of action. Clearly, then, policy is simply a continuum of management decisions and, not surprisingly, the prime function of a manager is decision making.

The manager

A manager is only managing when he is making decisions; the rest of the time he may be administering or teaching or a variety of other things. What then are the essential factors in the decision making situation?

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The first is uncertainty. Unless there is a present or future uncertainty, there is no need for a decision. The objective of the decision is to remove the uncertainty.

The second is the authority to make the decision. This authority is based on the power of ownership regardless of the number of stages of delegation that may exist between the owners and the decision maker.

Third, there must be an objective towards which the decision will be directed.

Fourth is information on which to base the decision.

The "decider" (to borrow a term from Prof. Houlder Hudgins of MIT) will always be subject to many pressures. Basically there are five kinds:

(1) Pressure from above, from the source of power.
(2) Pressure from below, from the subordinate management team.
(3) Pressure from outside.
(4) Pressure from within, the decider's personal objectives.
(5) Pressure from behind, the pressure of time.

Of these, all but the third are common to the decider whether he be president or at the lowest management level. The nature and effect of the third increases in importance towards the top of the management chain.

Oddly enough the first pressure is likely to be the least troublesome. In being given delegated power, a manager is normally also given an objective and specific limitations. On the basis of these he is either free to decide or not.

The second pressure includes conflicting or differing factual information from the various branches of the enterprise, the personal influence of the individual members of the management team and the possible functional effects of alternative decisions on the operation of the enterprise.

The third pressure will include at the presidential level the influence of customers, competitors, trade associations, government agencies, the law, the general public, the local community, special pressure groups, suppliers and the financial community etc. At lower levels external pressure may be limited to that of other branches of the enterprise outside of the decider's area of authority.

Pressure from within is a measure of the man, and will be affected by his personal obligations, moral standards, environment, self-evaluation of talent and status, and most important by his motivation. A manager has committed himself to the enterprise. His personal success will be gauged by the success of the enterprise, and he expects to be measured by his superiors in terms of his contribution to the success of the enterprise. The common denominator in the motivation of all managers is the success of the enterprise as a whole.

Time presses on the decider in a number of ways. There is the basic immediacy of the decision. A decision cannot be deferred, it must be made now – and it always is, even if only in the negative sense of not changing the presently adopted course of action. (When someone complains about lack of a decision, he usually means lack of the decision he wanted.) This immediacy determines that a decision must always be made on the basis of the information available and the pressures felt *at the time*. This implies that there will always be a number of unknowns so that the decision will be a kind of hypothesis dependent to some degree on the experience and intuition of the decider.

Then there is the relationship of the decision to the over-all time scale. A decision is a bridge between the past and the future. The information and circumstances on which the decision is based are products of the past. But the decision can have no effect on the past, it cannot be retroactive, it looks only to the future; and the future usually poses a further problem – the conflict between short range and long range objectives. A decision should normally be directed to satisfy, as nearly as possible, the requirements of both objectives, but often enough the short range objective will have to be passed over in favour of the more distant future. Decisions by default are usually short range because the course of action is determined without recognition of the long range objectives. In an enterprise, if the preponderance of decisions are short range, then an essential ingredient of management has been lost. The enterprise is simply reacting to present conditions and the positive action of controlling and shaping the future is forfeit.

The objective of this very brief review of the management function has been to identify the principal factors that determine the attitude of a manager.

These can be conveniently summed up as follows:

(1) A manager's function is to make decisions and in so doing he is constantly faced with uncertainty.
(2) The predominant factors with which he deals are money, time and people.
(3) A manager's personal satisfaction and standing are dependent on the success of the enterprise as a whole.

ENGINEERING

The function of engineering is probably more uniformly understood than that of management. I believe the following definition will be generally accepted:

"Engineering is the function of converting or applying the forces of nature for the benefit of man."

This definition identifies the essential features of engineering as follows:

(1) Engineering (like management) is an active function.
(2) The primary objective is the physical result – the product or the process.
(3) The prerequisite for engineering is knowledge.
(4) Engineering must seek for continuing technical improvement – for perfection.

It has been suggested that a management is a functional entity. Engineering within a given enterprise is not however a self-contained whole. Viewed from the outside, the quality of an engineering organization will not normally be judged from the annual report, but will be gauged by the technical excellence of the product and the collective competence of the group as evaluated by other engineers. Engineering is a universal function and its standards tend to be absolute.

The importance of knowledge in the engineering definition warrants some further examination. An alternative, but not now so popular, term for engineering is applied science. Science simply means knowledge, or

more specifically, an organized body of knowledge in a designated field. The difference between science and engineering is the seeking of knowledge for its own sake as compared with seeking of knowledge for the purpose of applying it for practical purposes. The need for knowledge and the search for further knowledge is essential in both cases. I emphasize this knowledge factor because it is the basis for professionalism in engineering (as it is also in the law, medicine etc).

The engineer

A man (or woman) who professes to have the appropriate special knowledge and who can satisfy the academic and technical bodies as to his competence qualifies as a professional engineer.

The engineer considers himself and is expected to be an expert in his field. To maintain the status of an expert is a difficult task. The ever-expanding body of technical knowledge makes an increasing degree of specialization inevitable but, even so, just to keep up to date requires continuous study and the opportunity for exchange of views with others in the same field.

What motivates an engineer to keep up to date in his field? First there is an interest in the subject *per se*. Most engineers get real enjoyment out of exercising or increasing their knowledge. Second, there is the hope of making a contribution or discovery, of finding a better solution or novel application, of expanding the field of knowledge, of creating something new. Finally there is the badge of success that comes from recognition of his work by his fellow experts.

In industry, the essential function of a professional engineer – equivalent to the decision-making function of the manager – is that of question answering or problem solving.

Left to his own devices, how will an engineer approach a problem-solving situation?

First he will identify all of the factors that affect the problem. On the basis of his knowledge and rational analysis he will determine the theoretical relationship between all of these factors, and by combining these produce a unique and exact solution. If some of the factors or relationship are unknown, he will conduct experiments to identify and measure them. When he has reached the theoretical conclusion, he will test it to prove that it is correct.

To an engineer answers are the inevitable result of the stated circumstances; they are right; they are accurate; they can be proven.

Without searching further into the function of the engineer, the principal factors affecting his attitude are recognizable:

(1) An engineer's function is to solve problems and in so doing he relies on his own knowledge and accurate quantitative analysis.

(2) He deals predominantly with facts and the predictable physical world.

(3) His personal satisfaction and standing depend largely on the reputation he commands among his fellow experts through the technical excellence of his work.

I have purposely taken the opposite poles in the foregoing parallel sketches of the manager and engineer. You may find them a little extreme, but I believe that they properly indicate the reasons for and nature of the basic conflict in attitudes between the professional and the manager.

It is only by admitting the existence of this conflict and by holding it up for inspection that any progress will be made in dealing with the problems it creates – and, in fact, in taking advantage of the benefit it can produce.

Thirty-five years ago, before many of the presently accepted principles of management or industrial psychology were popular, Mary Parker Follett presented a paper before the Bureau of Personnel Administration entitled "Constructive Conflict"[2]. Miss Follett had developed a philosophy that any continuously productive industrial organization must be based on a recognition of the motivating desires of the individual and the group, and must strive for an honest integration of all points of view so that each individuality might be mobilized and made to count both as a person and an effective part of the group. In the particular paper referred to she was examining the three main ways of dealing with conflict: Domination, Compromise and Integration.

In the situation we are now examining, domination cannot be appropriate. Domination implies a head-long collision and victory of one side over the other, and this does not fit the kind of conflict that has been described.

Neither is compromise an adequate approach. Compromise implies two opposing parties separately reaching their own conclusions and then trading off their differences. Compromise is the mechanism of the market place. A compromise solution does nothing to alter the initial views of the participants and must leave both parties dissatisfied, since each must have given something up in the process. One can hardly imagine a manager trading some profits for some technical perfection on a straight bargaining basis. A conflict solved by compromise is sure to become a problem again.

The integrative approach to dealing with conflicting views is the one which holds the possibility of success. The psychology of integration is a rather complex matter if pursued in detail, and is well beyond the scope of this discussion. In terms of the engineer-management relationship, integration means the establishment of objectives which will provide satisfaction of the desires of both sides. Such objectives will be established by first identifying the different individual desires – as I have attempted to do earlier in general terms – and setting them down side by side in the open so that they can be compared and evaluated. In the process of evaluation it is inevitable that there will be some spontaneous revaluation or modification of desires on both sides to the point when a mutually satisfactory objective results.

It is clear that this approach to dealing with conflicting desires requires intelligence and understanding. It follows then that the key to the integrative approach is communication.

Now there is really nothing new about all this, and some of you are no doubt wondering why I have taken the trouble to provide this theoretical excursion. It is solely because I feel there is a need to sit back and think out loud about these things from time to time – to remind ourselves of the underlying factors before we plunge in to deal with the day to day situation.

THE SPECIALIST

Returning to the engineer-management situation, many of the desires of the professional can be satisfied by the simple process of providing a career path for him as a professional contributor. Often the only avenue for promotion within an organization is into a managerial position. On accepting such a promotion a professional either continues to concentrate on his special field and does a poor job as a manager, or finds his status as an expert slipping away while he concentrates his efforts on distasteful administrative functions. To promote a professionally oriented person in this way will destroy a good professional and quite frequently create a poor manager.

What is needed is the opportunity to advance as a specialist on a path parallel to the managerial one. This means setting up specialist positions with titles — and remuneration — that recognize the value of the specialist's individual contribution to the enterprise and where the relationship of the specialist to the junior engineer is that of teacher to student and to the manager is that of consultant. Junior engineers who show the inclination and capacity to advance along this path should be encouraged to participate in the work of professional societies and to further their education and professional competence and should be recognized for their accomplishments. Their work assignments should be structured so as to take advantage of their growing professional skill, for example, by attaching them as special assistants to the managers of smaller organizational groups, or by assigning them minor research projects.

The process of integrating such specialists with the enterprise as a whole need not be difficult. Since they will not be expected to make managerial decisions they do not need to be aware of or understand in detail the workings of the whole enterprise. They do need however to be aware of the objectives of the enterprise and, most important, of how their contribution has affected the attainment of these objectives. One of the functions of specialists is to be the source of new ideas, and it is unlikely that such new ideas will be in harmony with over-all objectives if the objectives are unknown. One way to effect integration of new ideas with over-all objectives is to have the senior specialists participate with the Sales, Financial and other managers in the preparation of research and development programs and budgets, and product development planning. Such organizational devices can serve greatly to augment the day to day communication between managers and specialists.

The use of the professional specialist as noted above will do much to enlarge his contribution to the enterprise and at the same time to satisfy his individual desires in concert with the over-all objectives.

THE ENGINEER MANAGER

Many engineers, however, will have an inclination to enter the management field, and the enterprise will have need for engineer managers. It has been estimated that 40% of all professional engineers eventually become managers[3]. It is my contention that this proportion will tend to rise for two reasons:

(1) There is an increasing need for managers of engineering work itself and this can in general only be satisfactorily done by engineers.
(2) In the higher or broader management functions there is an increasing need for managers who can quickly grasp the technical factors and problems of industry.

Engineers who aspire to or are expected to advance into management, must be trained for the job. This training should include on the one hand the acquisition of knowledge and on the other the development of a managerial attitude.

There is much that the engineer can do for himself in this regard. Management is an integrative process and I have tried to point out that the keystone of integration is communication.

Engineers should therefore learn to express themselves both in writing and orally. They should school themselves to be concise and to use terms that will facilitate understanding by persons with less expert knowledge.

Communication involves a receiver as well as a transmitter. Managers have to be familiar enough with all phases of the enterprise so that they can understand inputs from any function. It will help immeasurably in this understanding if the engineer will study the principles by which the other special phases of the enterprise are governed. It is not necessary to become expert in all of these, but some reading in the fields of accounting, inventory control, budgeting, and so on can only be helpful. Engineers are familiar today with the "systems concept" of engineering. The manager's system is the enterprise, and increasing familiarity with all components of it is necessary at successive management levels.

The influence of people on managers has been outlined. In order to deal with people in other areas it is necessary not only to know what they do, but why. The easiest way I know to acquire an estimate of the other fellow's point of view is by informal association. Engineers should make some effort through social activities, at the lunch period or even driving to and from work to talk to their associates in other departments about the work situation.

Management too must take steps towards the training of managers. As far as the professional engineer is concerned, it must first be recognized that there should be alternative career paths, either specialist or managerial, and that the choice between these must be made at a relatively early stage. This means that personnel assessment procedures for engineers should provide for identification of the inclinations and capacities for these alternative courses.

For those tending toward the management path, job assignments should be as varied as possible and chosen to bring the engineer into contact with a variety of the non-engineering phases of the enterprise. He should be provided the opportunity to serve occasionally on a team or group assigned to solve a general company problem. These will provide an opportunity to learn how different people act and react in the working environment.

These engineers should be encouraged to continue their education just as much as the specialist, but in the non-engineering fields.

Jobs for these people should be structured so as to give them the opportunity to think and act as managers[4]. At the beginning the jobs must of necessity be predominantly technical, but as experience is gained the job should be enlarged by providing time for participation in administrative tasks — preparation of budgets and schedules, estimating etc — which introduce subjective problems and the opportunity for making or recommending management decisions.

I indicated earlier that the individual making a management decision was subject to internal pressures. Since the most important decisions are made by the senior managers, an awareness of the personal attitude of top managers will be of great assistance to junior managers in understanding and keeping in step with top-level decisions.

A device for manager development which attracts me consists of permitting small groups of junior managers from different branches of the enterprise under informal after dinner circumstances to question and discuss with top managers current general problems or conditions affecting the enterprise.

CONCLUSION

These have been at the best some random thoughts on this very important subject. In closing I would like to summarize them briefly.

As a result of formal training, habit or inclination there is a basic conflict in attitudes between management and the professional employee. The existence of this difference is not bad, it is in fact necessary to the accomplishment of objectives in a progressing industrial organization. Utilization of the various motivating desires depends upon setting objectives for individuals and groups which provide satisfaction for the employee and at the same time are in harmony with the over-all objective.

Such individual objectives will tend to be self generated if there is an adequate communication of ideas within the organization.

Communication cannot be effected by issuing orders and instructions or just by passing messages. Real communication depends on understanding. Establishment of real communication will be facilitated by the arrangement of work assignments that recognize the needs of the individual, allow him to enlarge his view of the enterprise and thus provide receptiveness to communication. Advantage should be taken of the "informal organization" in this respect[5]. Re-examination of the examples cited at the beginning of this paper will show that they are all the result of faulty communication.

It is encouraging to note that a single approach will produce the desired results in both of the areas we have been discussing:

(1) improved utilization of the professional employee in the enterprise, and

(2) the development of engineer-managers.

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RECENT ADVANCES IN AIRCRAFT FUELS†

by R. G. Davies*

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SUMMARY

The paper discusses recent specification changes for aviation gasolines and then outlines the evolution of military specifications for aircraft turbine fuels. Some of the more important turbine fuel properties, such as burnability characteristics, freezing point, volatility as well as the effect of trace materials, are discussed in the light of operating experience. Civil and the more recent military turbine fuel specifications are described and probable future trends outlined. General aspects of high energy fuels for jet engines are considered and the advantages and disadvantages of both slurry fuels and borane fuels are pointed out. The paper concludes by briefly describing fuels for rocket engines.

INTRODUCTION

THE TITLE "Recent Advances in Aircraft Fuels" in itself poses something of a problem. In the first place, it is necessary to know the definition of an aircraft and, in these days of sophisticated and expensive fireworks and orbiting dogs and monkeys, this is rather difficult. In the second place, it seems in retrospect that some of the changes in aircraft fuel specifications, in recent years, can hardly be considered advances. However, this paper describes recent specification changes for aviation gasolines and the more conventional turbine fuels, discussing some of the critical properties and concludes by considering high energy fuels generally and fuels for rocket engines.

AVIATION GASOLINES

The specifications established for aviation gasoline grades have been generally unchanged for about 15 years. Some six years ago, the US military required the addition of fuel soluble corrosion inhibitors to their gasolines. These materials don't enhance the properties of the fuel in any way, as far as the engine is concerned, but they reduce corrosion of the fuel distribution system up to the airport by "plating-out" on the walls of pipelines, storage tanks etc, to form an oily film which retards rusting. In some airline operations, certain of these materials gave rise to blower and induction system deposits and, because of this, corrosion inhibitors were soon left out of avgas supplies to commercial operators. Canadian specifications for avgas have never required the incorporation of a corrosion inhibitor.

Quite recently, a new requirement in the military specifications for 115/145 Grade avgas has been that the aromatics contents shall not be less than 5% bv. This requirement arises from a leakage problem in the integral fuel tanks of certain transport aircraft. The fuel tank Fairprene seals are of a rubber sandwich type construction which depend, for effective sealing, on the swelling of the rubber. Rubber swelling is increased by increasing temperature and aromatic content of the fuel. By juggling these two parameters, the military feel that a 5% minimum aromatics content will give essentially leak-free performance. Commercial operators of these aircraft usually use 100/130 Grade of avgas, which contains more aromatics than 115 Grade, and have not experienced this problem.

A noticeable trend on the supply side of aviation gasoline is the gradual disappearance of 108/105 Grade low-lead fuel, since those engines which formerly used this grade now operate satisfactorily on 115/145 Grade. Similarly 91/98 Grade is now obsolescent. A complication which has arisen with the increasing commercial traffic between Europe and Russia is that Russian gasolines are a different colour from the rest of the world. Their 100/130 Grade, for instance, is bright orange instead of green and their 115/145 Grade is red instead of purple.

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Figure 1
Carbon deposits — combustor liner

†Paper read at the Mid-season Meeting of the C.A.I. in Edmonton on the 19th February, 1960.

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AVIATION TURBINE FUEL

Early developments

The early development of the aircraft turbine engine in the UK used common-or-garden lamp grade kerosene. In the USA early jet engine development also used a kerosene fuel to specification MIL-F-5616, better known as JP-1. However this was anything but a common kerosene, because the specification called for a –76°F freezing point while retaining a high flash point. Kerosenes, irrespective of end-use, normally have freezing points of about –30°F to –65°F, and it was soon realized that JP-1 described a fuel which was of inadequate availability for military requirements. The JP-1 specification was withdrawn some years ago, but unfortunately the name persists, and aviation kerosene is still often loosely referred to as JP-1 when JP-1 really means a very special kerosene indeed. Therefore the "wide-cut" gasoline, or "wide boiling range" fuels, were specified for military use. Fuels of this type contain both naphtha and kerosene fractions. From 30% to 40% of crude oil can be turned into wide-cut fuel if necessary. The first fuel of this type was JP-3;

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Figure 2
Carbon deposits — vapourizing tubes

but this has now been almost entirely superseded by JP-4 – of lower volatility to eliminate fuel boiling and vapour lock in the engine fuel system under rapid climb conditions. JP-4, as covered by the equivalent US, British or Canadian specifications (the latter being 3-GP-22c), has been for some time the principal fuel for military turbine aircraft.

The other well-known military fuel is JP-5, which is really a high flash point kerosene (minimum 140°F flash point). This fuel is designed for storage in outboard tanks of aircraft carriers with the idea that the high flash point would minimize fire hazard in the event of a torpedo strike. When mixed with aviation gasoline in the ratio 2 or 3 to 1, a fuel approximating to JP-4 in general properties is produced, when desired, for the carrier-borne jet aircraft.

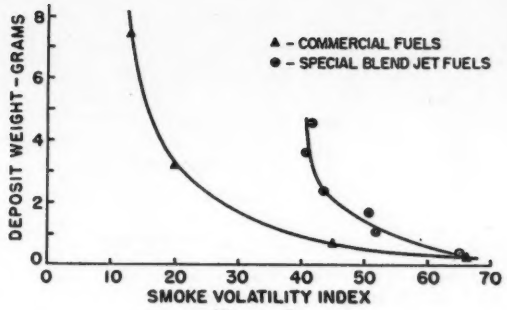


Figure 3
Smoke volatility index versus carbon deposits

Certain turbine fuel properties have become important with the evolution of more recent specifications; these are discussed below.

Burnability

The "burnability characteristics" of an aviation turbine fuel is a wide term embracing such factors as carbon deposition, combustor liner temperature, tendency to smoke etc, and many investigators have attempted to correlate these performance characteristics with specific fuel properties e.g. smoke point, smoke volatility index, aromatics content and diaromatics content. Smoke point is the maximum height of the wick in millimeters in a special lamp that will just permit smoke-free burning of the test fuel. Smoke volatility index is a mathematical correction applied to smoke point in an attempt to better predict full scale performance; numerically it equals the smoke point plus 0.42 of the volume per cent evaporated under 400°F. Diaromatics content is a direct measure of the high boiling aromatics of which the simplest member is naphthalene. Pratt & Whitney have felt that diaromatics contents of 3% by volume or less are necessary for good burnability characteristics.

Figures 1 and 2[1] show carbon deposits on combustor liners and vaporizing tubes. Figure 3[1] is some early data showing the relationship between carbon deposit weight and smoke volatility index in one particular combustor. Figure 4 shows the relationship between naphthalene content (or diaromatics content) and combustor liner temperature[2].

Because of the data shown in Figure 4, and similar data for smoke point, Pratt & Whitney specified 25 minimum smoke point or, alternatively, 3% maximum diaromatics,

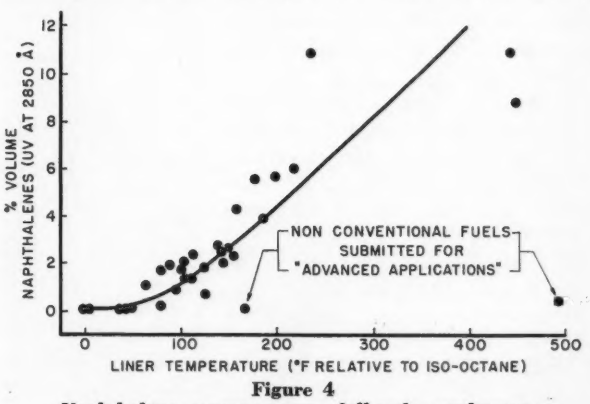


Figure 4
Naphthalene content versus full-scale combustor liner temperature

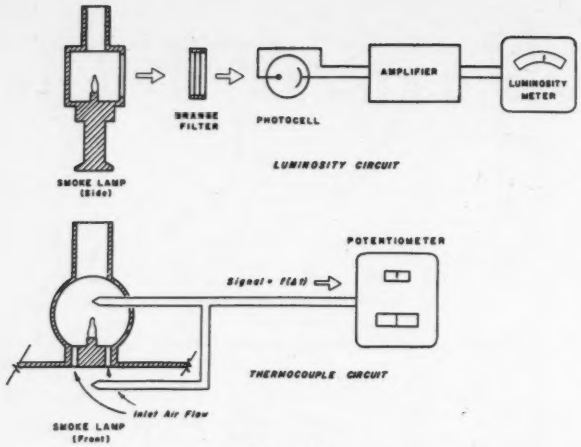


Figure 5
Fuel luminometer

and most commercial users of P & W engines have adopted these criteria. More recently, Pratt & Whitney have concluded that flame luminosity is an important factor, particularly in connection with the life of high temperature components such as flame tubes, nozzle guide vanes, turbine blades etc; this does not appear to be true for some other manufacturers' engines.

Pratt & Whitney have developed an apparatus known as the Luminometer, to assess the luminosity characteristics of turbine fuels. The apparatus, Figure 5, consists of a smoke point lamp instrumented to measure the luminosity of the flame and the temperature rise across it[2]. The performance of the fuel under test is compared with that of tetralin (which is allocated a "luminometer number" of 0) and isooctane (allocated a "luminometer number" of 100). Figure 6 shows ASTM smoke point versus liner temperature, and Figure 7 shows luminometer number versus liner temperature. Figure 8 shows aromatics and diaromatics plotted against luminosity number.

It seems likely that Pratt & Whitney will reissue their turbine fuel specification and specify a luminometer number of 50 minimum. Current aviation kerosenes have luminometer numbers of 45 to 58, whilst current JP-4 fuels, which are predominantly straight run, have luminometer numbers of 70-80.

Fuels of very high luminometer number offer the possibility of much longer overhaul life of the hot components of the engine. Such fuels are not at present generally available and their luminometer numbers dictate their chemical composition, so that they would necessarily be fuels in the JP-4 volatility range. This means that such fuels may not be operationally acceptable for other reasons.

Fuel burnability characteristics are very much a function of combustion chamber design. For example, some manufacturers use high-pressure fuel systems, which produce very efficient atomization, together with combustor designs which emphasize recirculation in the primary zone, resulting in an engine which is much less sensitive to these fuel properties. Against this, high pressure fuel systems have the disadvantage of being more sensitive to contaminant in fuel.

Thermal stability

With certain engines the fuel gallery lines are subjected to heating by their proximity to very hot engine parts. Fuel decomposition deposits can form in these gallery lines, on the nozzle screens and on the ports and orifices of the nozzles.

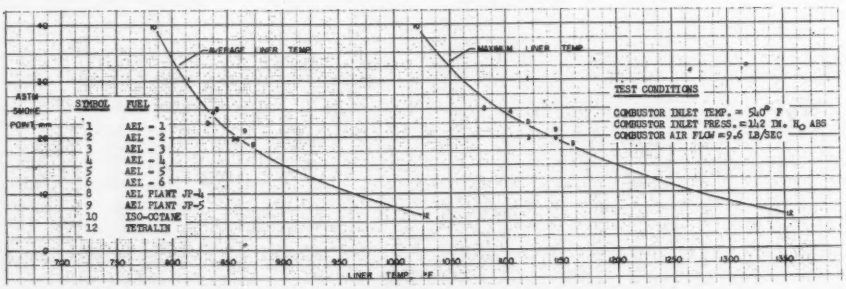


Figure 6
ASTM smoke point versus combustor liner temperature

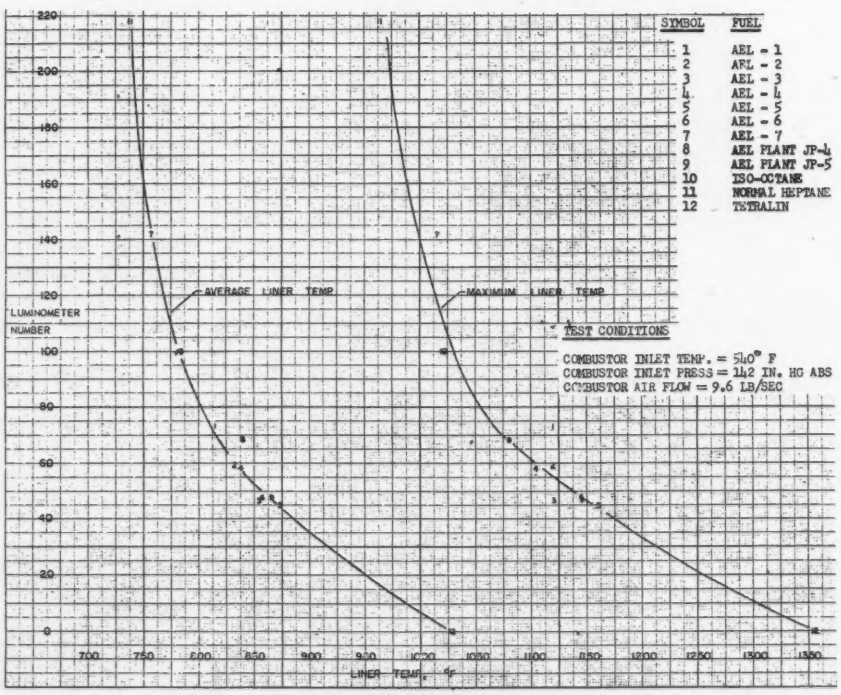
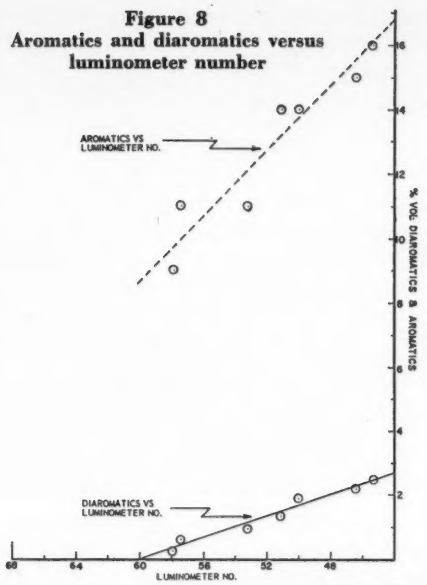


Figure 7
Fuel luminometer number versus combustor liner temperature

Figure 8
Aromatics and diaromatics versus luminometer number



The question of thermal stability of fuels also arises in other contexts. These involve the use of fuel as a heat sink, either for cooling engine oil, as in many of today's jets, or for cooling other components heated by ram temperature rise in high Mach number aircraft.

Thermal stability is measured in a piece of test equipment known as a CFR fuel coker. Fuel is pumped over a heated tube and through a sintered metal filter (Figure 9). Test criteria are pre-heater tube deposits and pressure drop across the filter; the usual test temperature conditions are 300°F pre-heater temperature and 400°F filter temperature, and this test is now incorporated in many military and civil jet fuel specifications. The test is being developed for much higher temperatures for predicting thermal stability of fuels for use in very high Mach number aircraft.

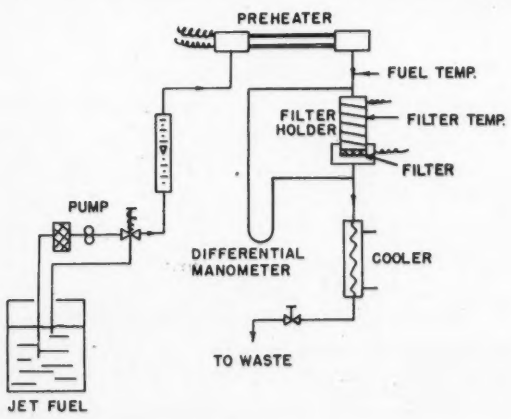


Figure 9
CFR (erdco) fuel coker

Low temperature properties

The danger of wax formation in the aircraft fuel system causing failure of fuel to feed to the engine was widely discussed when establishing the freezing point requirement for aviation kerosenes for civil jets. Considerable in-flight fuel temperature data now exists, and some of the earlier dire prognostications have not been borne out. The lowest fuel temperature reached by Pan-American, in their Boeing 707 operations over the Atlantic, so far is –38°F[3].

Last winter, Canadian Pacific Air Lines produced some interesting fuel temperature data for their North-Pacific and Polar operations with the Britannia aircraft. This represents the most critical case for in-flight fuel cooling, because the operational altitude of the aircraft is nearly as high as for pure jets but due to the aircraft's slower

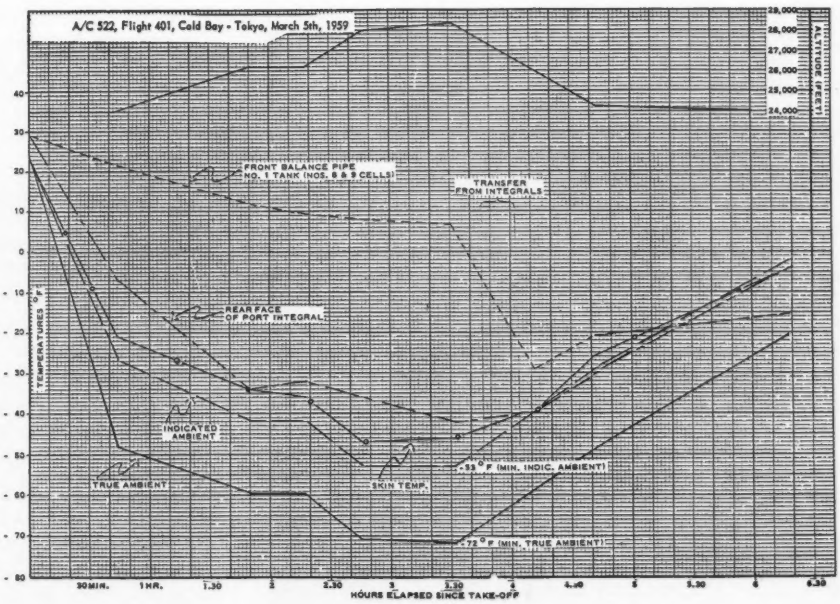


Figure 10
In-flight fuel cooling data — CPAL Britannia

speed the kinetic heating effect is much less. Figure 10 shows some of the data obtained[4]. Extrapolating measured minimum fuel temperatures for Arctic minimum temperatures, it is possible, but very unlikely, that in-flight fuel temperatures as low as about –60°F could be reached. Now most commercial aviation kerosenes are supplied against specifications requiring freezing points of about –50°C (–58°F). Freezing point is defined either as the temperature at which wax crystals separate on cooling (British and Canadian test methods) or, in some specifications, as the temperature at which the fuel becomes a "slurry" of crystals (ASTM method used in the USA). This latter temperature is usually about 7°F lower than the former. It is now agreed by the majority

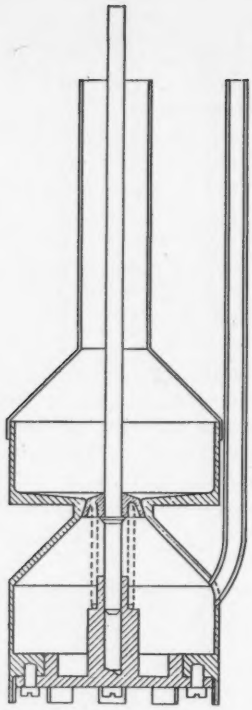


Figure 11
Thornton cold flow tester

of airline operators that a fuel heater must be installed ahead of the low pressure fuel filter to prevent clogging by ice crystals, which may occur at fuel temperatures below 32°F. If the aircraft is fitted with such a heater, the limiting temperature of pumpability is no longer indicated by the freezing point of the fuel but by the temperature at which the fuel is able to slump into the inlet of a fuel tank booster pump. This property is better measured by an apparatus such as that shown in Figure 11[5]. This equipment, known as the Thornton Cold Flow Test Rig, correlates very well with mockup aircraft fuel system tests and is currently being evaluated with the idea of replacing freezing point in turbine fuel specifications. Test fuel is put in the top chamber, the apparatus is cooled down and a spring-loaded valve opened for a 10 second period. After removing from the cold bath, the amount of fuel transferred from the top chamber to the lower chamber is a measure of the low temperature "flowability" of the fuel being tested. The test may be repeated, successively lowering the temperature; the point at which 50% holdup of the test fuel occurs usually being taken as the low temperature limit of the performance of the fuel.

Civil turbine fuels

Because turbine fuel represents about 40% of an airline's direct operating expense, in the case of large jet aircraft, the commercial operator has, more than ever before, looked very long and hard at fuel costs. An outcome of this has been a host of turbine fuel specifications, many of them written by the airlines themselves, but based to varying degrees on guidance specifications put out by such bodies as ASTM and IATA and on the recommendations of the principal engine manufacturers. A recent count showed 20 specifications for civil turbine fuels – there are probably more! This is in addition to something like 15 different US, British and Canadian military specifications for jet engine fuels. Of course in many cases these specifications are identical but all too frequently they differ in minor details.

Basically the airline operator has had to choose between a wide-cut gasoline (JP-4) or a kerosene type fuel, the choice being complicated by the fact that tax laws in some countries may favour one type at the expense of the other. Apart from this, the main factors to be considered are the differences in the heat content and specific gravity for the two fuels. Table 1 shows property data for the two fuels typical of world-wide supplies. Based on data of this sort, each operator works out range payload curves for his own particular route system and this together with fuel costs decides the choice of fuel.

Service experience to date, with both types of fuel, has shown that some fuel system components exhibit more wear and therefore have generally lower overhaul lives on JP-4 as compared with kerosene fuel. This is due both to the inherent poorer lubricity of JP-4 and to the fact that these fuel systems operated on JP-4 have a lower tolerance for dirt in the fuel than when operated on kerosene.

Fuel handling

During the last few years, the petroleum industry has paid considerable attention to the various aspects of turbine fuel handling to ensure delivery of clean, dry fuel to the aircraft and many precautions are taken during distribution, to this end. These include, in addition to filtration/water separation, provision for settling in conjunction with the use of floating suctions.

One result of the efforts in this field has been better general appreciation of how to realistically evaluate the performance of filters and filter/water separators. From this, the filter industry has devoted much effort to the development of equipment having more effective performance.

Despite this, filters and filter/separators occasionally fail in service, due usually to element rupture, faulty elements and/or faulty seals which permit by-passing.

TABLE 1
PROPERTIES OF AVIATION TURBINE FUELS

	Wide-cut Gasoline (JP-4, Avtag)	Kerosene (Avtur)
Specific gravity at 60°F	0.762	0.795
Btu/lb	18,720	18,650
Relative weight, lb/Btu	99.6	100
Btu/Imp gallon	142,650	148,240
Relative volume, gallon/Btu	103.9	100

Above figures are typical for world wide supplies.

Broad conclusions from above figures are:

(1) For all flights, *gallons of* fuel consumed will be 3.9% more with avtag than with avtur.

(2) Ultimate range will be 3.9% less with avtag than with avtur.

(3) For maximum takeoff weight the 100% payload on avtag will be greater by 0.4% of fuel weight. This extra payload gives marginally lower cruise speed.

Figure 12
Fuel monitor

Various fail-safe devices, designed as a final check on the whole handling procedure, which will shut the system down in the event of any such failure, are now under evaluation, and it is likely that the trend will be towards this type of hardware installed as near to the aircraft as is operationally practicable.

One such device is the fuel monitor developed by Shell/Streamline in the UK to positively prevent passage of fuel containing free water. This unit is currently being evaluated in various parts of the world with very satisfactory field performance to date; it is shown in Figure 12 and diagramatically in Figure 13[7]. If the fuel contains free water, pressure drop across the sensing element of filter paper discs increases and the pressure unbalance causes the spring-loaded valve to shut, cutting off fuel flow.

Various types of fail-safe equipment to detect failure of filter ability to remove solid contaminants from fuels are also being evaluated in the field. One approach which looks very promising is the "Turbomonitor" developed by Purolator of Canada (Figure 14). This unit is designed to be fitted to the fuelling hose nozzle and is essentially a very fine metal mesh screen, having absolute cut-off characteristics and designed to provide an acceptable pressure drop at normal fuelling flow rate. When the main filter is performing satisfactorily, the fine screen does not clog up over a reasonable life period but if the main filter should fail and pass excessive amounts of dirt the screen quickly blocks and the flow drops to an unacceptable level.

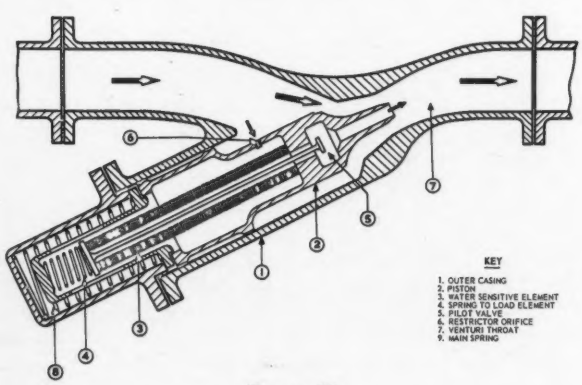


Figure 13
Fuel monitor (schematic)

TRACE MATERIALS IN TURBINE FUELS

Current turbine fuel specifications attempt to limit directly or indirectly minor or trace components present in all fuels which are known or believed to adversely affect aircraft performance and reliability. Such components include potentially reactive material in the fuel such as corrosive sulphur, mercaptans, gum and olefins or gum forming compounds.

Naphthenic acids

Commercial experience has shown that other materials not normally covered by existing airline or military specifications may often be present in turbine fuels and are potentially a source of trouble. For example, turbine fuels usually contain trace amount of naphthenic acids – very weak organic acids which do not react under the test conditions of the acidity or neutralization number requirements of most turbine fuel specifications.

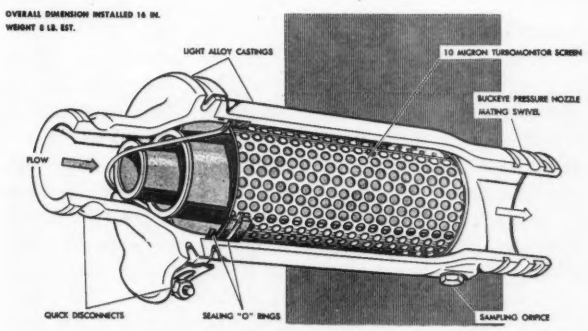


Figure 14
Purolator of Canada turbomonitor

These acids can react chemically, however, with various materials with which the fuel comes into contact during distribution from the refinery until it has been consumed by the aircraft. Such materials include the iron of pipes and tanks, sodium from caustic treatment at the refinery or from pipeline corrosion inhibitors and cadmium from plated surfaces in the aircraft fuel system. When the products from such reactions are fuel-insoluble, deposits are formed. Such deposits have been identified in kerosenes and, should such a situation remain unchecked, serious service problems due to filter blocking could undoubtedly arise. Good housekeeping practices at the refinery and through the distribution system guard against this sort of situation; in addition, the refiner often uses more comprehensive and stringent manufacturing specifications than those against which the product is supplied[8].

Copper and metal deactivator

Most distillate fuels contain trace amounts of soluble copper. This may be present in the crude, it may arise from refinery treating processes or from copper pick-up from valves, pumps etc during distribution. These copper

compounds may, in some cases, adversely affect certain fuel properties such as thermal stability, colour and gum stability and, because of this, specifications permit the addition of one of two types of metal deactivators. These materials chemically react with the soluble copper making it inert.

During last summer, one large operator in Europe experienced an epidemic of engine low pressure fuel filter blocking, eventually shown to be due to the copper complex of the particular metal deactivator being used in the fuel from both principal suppliers. This had only very limited fuel solubility and it was felt that fuel cooling in flight resulted in separation of the copper deactivator complex which was swept along the aircraft fuel system to the engine fuel filter where, indeed, its presence was confirmed by chemical analysis. The reason that no similar problem has been reported in North America is probably due to the fact that the other of the two types of approved deactivators is commonly used here and it is known that the copper complex derived from this type of deactivator is much more fuel soluble.

Because of instances of these kinds, even more comprehensive control of trace materials in turbine fuel can be expected in future.

Sulphate-reducing bacteria

Another field problem shown due to trace materials, but in a rather different manner, has been that due to the nefarious activities of sulphate reducing bacteria which inhabit the water layer that is sometimes present at the bottom of fuel storage tanks. These particular bugs have the unfortunate habit of relying for nutrition on naturally occurring inactive sulphur compounds which they convert into hydrogen sulphide gas. This dissolves in the fuel, putting it off specification and making it corrosive to metals such as copper and silver. The result may be corrosive attack of these metals in aircraft fuel system components.

This problem is now well recognized and is catered for by eliminating water bottoms and good housekeeping programmes in keeping tanks clean.

STATIC ELECTRICITY

One aspect of turbine fuel behaviour which has only recently been investigated in relation to aircraft useage is the development of static electricity during the high velocity flow of fuel such as during an aircraft fuelling operation. All fuels show this effect to some degree and the electrostatic charge is considerably increased by high velocity flow of fuel through a filter. It is possible to eliminate the electrostatic charging hazard by incorporating additives in the fuel to increase its conductivity[9]. The most effective additives found so far have the disadvantage that their effect diminishes with time and with movement of fuel from the refinery up to the aircraft, but work on this approach is continuing.

Experience in fuelling turbine aircraft and the limited experiments carried out so far have not indicated that refuelling existing aircraft at maximum rates with specification fuels produces a sufficient charging effect to cause a significant hazard. It is hoped to conclusively establish whether or not this hazard is a real one in experiments now being conducted in the USA and UK.

Two factors are important here: one is design of the aircraft fuelling system to ensure that the various components are not insulated from one another or from the aircraft structure and to ensure a minimum of fuel splashing and spraying during fuelling. The other is to ensure that the fuel is not contaminated with materials which increase the current generating tendency without similarly increasing the conductivity. Instances are on record where contamination with lube oil has caused such a behaviour. In this case, increased charge separation and, therefore, a greater voltage build-up occurs.

Because of the work done on electrostatics in the petroleum industry, procedures for minimizing explosion hazards while filling refuelling vehicles are now established. These involve avoidance of splash filling and initial fill rates corresponding to pipe velocities not exceeding 3 ft/sec.

RECENT MILITARY FUEL SPECIFICATIONS FOR ADVANCED APPLICATIONS

For very high speed aircraft, fuel volatility becomes of fundamental importance.

Turbine engines control fuel flow (engine power) by varying the fuel pressure delivered to the spray nozzle. For low power cruise, or operation at high altitudes, all systems fundamentally reduce the fuel flow by reducing the fuel pressure at the nozzle. If the fuel temperature becomes high enough, the flow to the nozzle becomes

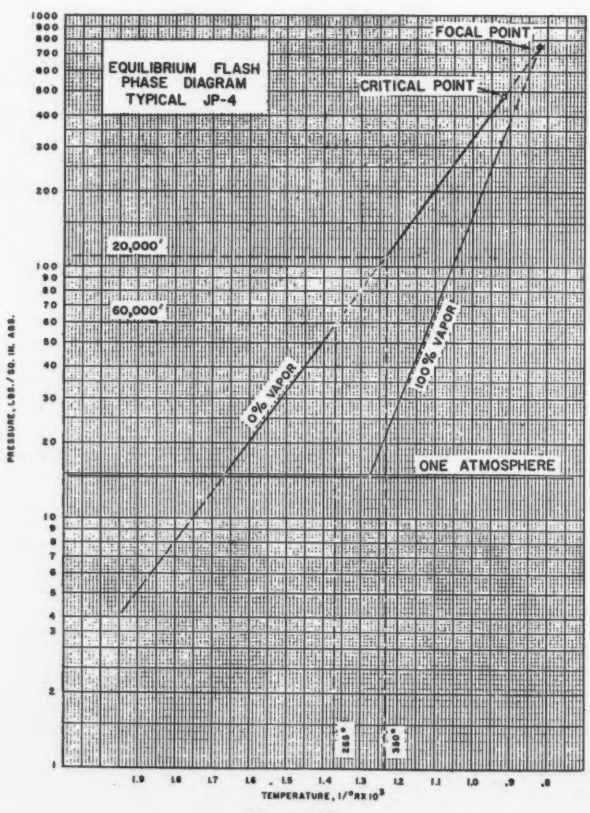


Figure 15
Equilibrium flash phase diagram, typical JP-4

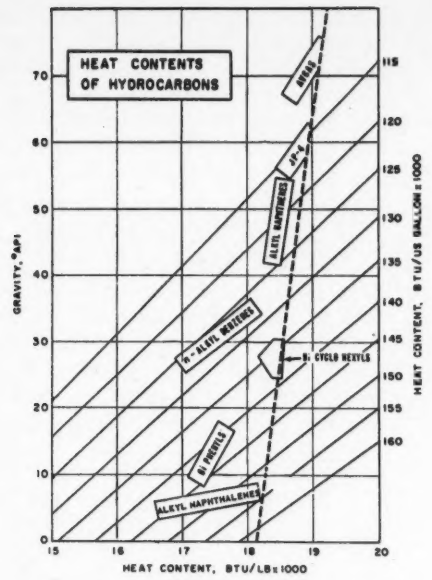


Figure 16
Heat of combustion and density of various hydrocarbons

mixed with vapour and faulty engine operation results. This problem becomes acute at altitudes and speeds which are now being realized.

As a typical example of this problem we may use the following values:

Altitude, feet	Fuel pressure, psi, abs
20,000	110
60,000	60

From the Flash Equilibrium Phase Diagram (Figure 15), used to predict the pressure necessary to keep the fuel liquid at high temperature, it is determined that the fuel (JP-4) temperature must not exceed 350°F at 20,000 ft and 265°F at 60,000 ft. These fuel temperatures in turn can be converted to individual weapon Mach number limits from the weapon design information.

There is a rough correlation between a fuel's high temperature properties and its low temperature properties. For instance, fuels containing low boiling fractions to obtain good low temperature properties, such as JP-6 as presently written, have markedly limited high speed utility as compared with the higher freezing point JP-5.

Nevertheless, the JP-6 specification, MIL-F-25656, has been evolved with these general volatility considerations in mind. JP-6 is a "wide-cut kerosene" fuel, that is, it is similar to "wide-cut gasoline" or JP-4, but is of lower volatility. JP-6 is the fuel chosen for the engine development programme of the J-93 powerplant scheduled to power of the B-70 Valkyrie Mach 3 bomber. It is doubtful whether fuel to the present JP-6 specification will ever be produced in significant quantities. In fact, it is becoming increasingly apparent that high supersonic (Mach 3+) applications will require fuels of lower volatility. New specifications will have to be evolved to completely describe such fuels, but it would appear that about 50 psi max VP at 500°F, adequate thermal stability at 550°-600°F and possibly high luminometer number will be the prime requirements.

The other military hydrocarbon fuels of significance are those specified for ram jet and rocket engines and covered respectively by Specification RJ-1, MIL-F-25558, and RP-1, MIL-F-25576.

These specifications call for much more closely controlled materials than are permitted by the relatively wide specific gravity limits of JP-4 and commercial aviation kerosene specifications. RJ-1 and RP-1 are essentially kerosenes which have been highly extracted to remove nearly all of the aromatics. The much tighter specification limits reduce the variation in physical characteristics between different batches of fuel and this allows missile performance to be more accurately predicted. The logical extension of this philosophy is to burn pure compounds, and certain hydrocarbons which can be synthesized by the petro-chemical industry are currently of interest in ram jet applications; materials of this type are diethyl cyclohexane and isopropyl bicyclohexyl.

HIGH ENERGY FUELS

The heat energy of different types of fuels is a function of chemical composition and for hydrocarbon fuels, whether derived directly from crude oil by conventional refining processes or tailor-made by synthesis of individual hydrocarbons, the limits of heat energy available are relatively narrow (Figure 16). Compared with some of the so-called "exotic" fuels which will be briefly discussed, however, hydrocarbon fuels have the outstanding advantages of low cost, availability and ease of handling. Let us first of all look at some typical high energy fuel components for use in air breathing engines (Table 2). This application includes conventional aircraft turbine engines, ram jets and after-burner installations. It is apparent that on a Btu/lb basis hydrogen is the ultimate fuel. Volume limitations make it necessary to use hydrogen in the liquid form and even here the very low specific gravity of liquid hydrogen (0.0708 at −423°F) makes it compare unfavourably with jet fuel, which requires only 0.25 of the volume for a given Btu content. The handling problems of liquid hydrogen – which boils at −423°F – are such that it is unlikely that it will ever be used as an aircraft fuel although it will

TABLE 2
HIGH-ENERGY FUEL COMPONENTS

Fuel	Physical State at 60°F	Specific Gravity	Heat of Combustion	
			Btu/lb	Btu/cu ft
Aluminum	S	2.702	13,310	2,245,000
Beryllium	S	1.85	29,140	3,365,450
Boron	S	2.3	25,100	3,604,000
Carbon (graphite)	S	2.25	14,090	1,978,700
Decaborane	S	0.78 at 212°F	28,300	1,379,000
Diborane	G	0.447 at-134.5°F	31,370	875,394
1-Ethylnaphthalene	L	1.008	17,020	1,074,800
HEF-3	L	–	26,000	–
Hydrogen	G	0.0708 at -423°F	51,660	228,000
Jet fuel (JP-4 or kerosene)	L	0.78	18,690	910,000
Magnesium	S	1.74	10,810	1,174,000
Pentaborane	L	0.61	29,130	1,110,000
Silicon	S	2.4	13,170	1,974,000
Titanium	S	4.5	8,190	2,300,000
ZIP: HICAL	L	–	25,000-27,000	–

Note: G, L and S means gas, liquid and solid, respectively

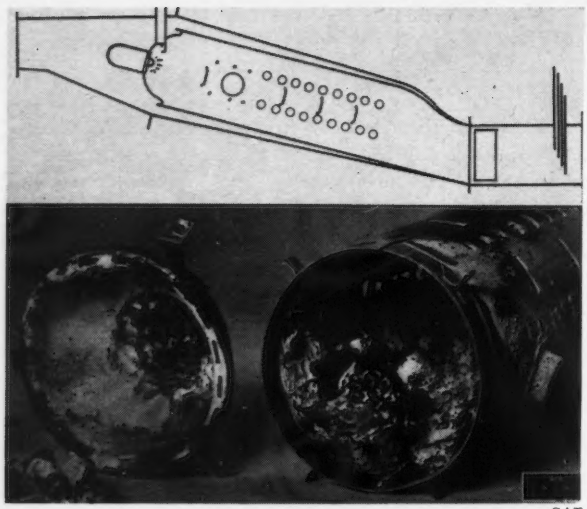


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Figure 17
Boron oxide deposits in standard turbojet combustor

probably be used in rocket engines for spaceflight applications[a].

Much practical work on high energy fuels for air-breathing engines has been carried out by the National Aeronautics and Space Administration. This work has followed two main approaches: (1) Slurry fuels, and (2) Borane fuels.

Slurry fuels

These are fuels in which metal particles 1 to 20 microns in size are dispersed in a hydrocarbon fuel such as JP-4. The mixture is thickened with petrolatum or aluminum soaps to reduce sedimentation of the metal particles.

Slurries of aluminum metal, attractive because of their high energy per unit volume, were soon discarded because the sticky molten aluminum oxide caused a very serious deposit problem in the combustion chamber.

Magnesium slurries, on the other hand, have been burned successfully and with high combustion efficiency in both after-burner and ram jet combustors[10]. Although magnesium, like aluminum, forms a very high melting point oxide, this does not stick to combuster surfaces. Magnesium slurries are easy to burn – they will in fact burn under very high altitude conditions where hydrocarbons burn only with difficulty. Because of the relatively higher heat content per unit volume, magnesium slurries can give up to 30% more thrust than hydrocarbon fuels. The relatively lower heat content per pound, however, results in an unacceptably high specific fuel consumption and the resultant shortened operating range.

Beryllium slurries are theoretically attractive, but the metal is scarce and the exhaust product, beryllium oxide, is extremely toxic.

Boron slurries have not proved successful, mainly because of low combustion efficiencies – generally less than 85%. To achieve good combustion efficiency, very high local flame temperatures are necessary and this results in destruction of engine parts. Attempts to keep combustor parts cool, in addition to reducing combustion efficiency, produced large deposits of boron oxide. This solidifies at 1100°F and up to 1750°F is very viscous.

Boron hydride fuels

Most of the recent work on boron fuels for air breathing engines has been with boranes (boron hydrides) or derivatives of these. At normal temperatures, di-borane is a gas, pentaborane is a liquid which is spontaneously flammable in air and decaborane is a solid. They hydrolyze or spontaneously decompose in the presence of moist air and have about the same toxicity as chlorine.

The handling problems of borane fuels can be eased by the introduction of a hydrocarbon alkyl group into the boron hydride molecule. The HEF-3 and HI-CAL project ZIP fuels, manufactured for the US military by Olin-Mathieson Chemical Corporation and Callery Chemical Company, are reported to be triethyl decaborane and triethyl pentaborane. Such fuels were scheduled for after-burner use in the GE J-93 engine, being developed for the B-70, but it is now reported that the borane fuel project has been scrapped.

NASA have done considerable work on borane fuels in turbojets, after-burners and ramjets, including flight testing. The major problem in turbojets, of course, was that of the combustion product, Boron Oxide B_2O_3 which is formed to the extent of about 2½ lb per 1 lb of borane fuel. At the turbine operating temperatures this material behaves like molten glass (Figures 17 and 18).

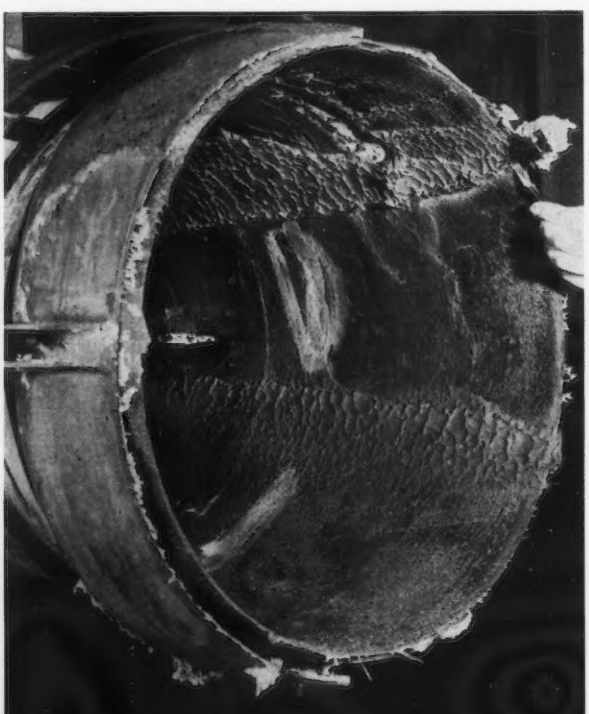

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Figure 18
Boron oxide deposits in turbojet engine: tailpipe and nozzle

[a]In mid-December 1959, the first announcement was made of the successful test-firing of the Pratt & Whitney, 15,000 lb thrust XLR 115-P-1 liquid hydrogen engine for the second stage of the Convair Centaur.

In after-burners and ramjets, one of the major difficulties involves the thermodynamics of the exhaust gases. At combustion temperatures above 3000°F, considerable heat goes into vaporizing boron oxide to an extent which largely dissipates the benefits of boron fuels.

Another major technical problem of borane fuels is their poor thermal stability and we have already discussed how importantly this property is now regarded for hydrocarbon jet fuels. In addition, synthesis of borane fuels is a costly multi-stage process, with no quick, cheap manufacturing method in sight.

In summary then, the application of high energy fuels to air breathing engines has not justified early hopes, for a variety of reasons.

ROCKET FUELS

When we can introduce chemical oxidants to achieve fuel combustion we enter a whole new field of propulsion chemistry. Rocket engines for aircraft application employ relatively safe, easy to handle fuels and oxidants but for missile applications, requiring the highest performance, the premium is for some of the most reactive (and therefore hardest to handle) materials known to chemistry. Such materials, in fact, are usually very toxic, corrosive and frequently explosive, all of which makes the operation of rocket motors an interesting pastime.

Much of the early rocket development has been with liquid fuels but because of handling and storage problems with the most frequently used oxidizers, such as liquid oxygen, high test peroxide and fuming nitric acid, resulting in an appreciable time period to fuel a rocket for firing, there has been a swing toward solid propellants. Another advantage of solid propellant rockets is that the propellant itself can form the combustion chamber walls until combustion is nearly complete and heating (and thus weakening) of the combustion chamber is less than with liquid fuels. However, temperature sensitivity and combustion instability have been problems with some solid propellant rockets; the latter results from cracking of the unburned propellant under the severe thermal stresses present. Also, as the propellant tank and combustion chamber are one and the same for a solid fuel unit, heavier construction is necessary which makes the ratio of propellant weight to total weight less than for liquid propellant rockets. Typical solid propellants employ ammonium or lithium perchlorate as the oxidizer with a thiokol plastic or hydrocarbon rubber containing metal as the fuel. Decaborane has also been used as the fuel component.

It seems quite possible that as an extension of the JATO principle we may see solid propellant rockets used as boosters for supersonic airliners.

More recently there seems to have been a swing back to liquid propellants – using "storable liquids". The technology of nitric acid, for example, has advanced to the stage where IRFNA or inhibited red fuming nitric acid is a material much more readily stored than the white fuming nitric acid which was originally used. IRFNA contains small amounts of hydrogen fluoride to reduce corrosion by forming a coating of metallic fluorides on the metal surfaces. It also contains appreciable amounts of water and nitrogen dioxide for stabilization against decomposition under conditions of long-term storage at high temperatures. Similarly, UDMH (unsymmetrical dimethyl hydrazine) when mixed with hydrocarbon fuels forms a relatively stable, storable fuel. HYDYNE (UDETA) fuel is a 60/40 mixture of UDMH and diethylene triamine which has about the same physical properties, storage and handling characteristics as alcohol, but with a 12% higher specific impulse. It was used in the Jupiter "C" satellites.

TABLE 3
FUEL/OXIDIZER COMBINATIONS FOR ROCKET MOTORS

Oxidizer	Fuel	Specific Impulse (Secs) at 500 psia	Combustion Temperature °F
IRFNA (1)	Aniline	235	5,100
IRFNA	Liquid ammonia	237	4,220
IRFNA	JP-4	240	5,200
Hydrogen peroxide	JP-4	248	4,830
IRFNA	Unsym. dimethyl hydrazine	250	–
Nitrogen tetroxide	Unsym. dimethyl hydrazine	255	–
Chlorine trifluoride	Hydrazine	255	–
Liquid oxygen	Alcohol	259	5,560
Nitrogen tetroxide	UDETA (2)	260	–
Hydrogen peroxide	Hydrazine	262	4,690
Liquid oxygen	JP-4	264	5,770
Liquid oxygen	RP-1	266	–
Liquid oxygen	UDETA	270	–
Liquid oxygen	Hydrazine	280	5,370
Fluorine	JP-4	282	–
Ozone	JP-4	283	–
Nitrogen trifluoride & fluorine, 50:50	Ammonia	295	–
Fluorine	Ammonia	306	7,224
Fluorine	Hydrazine	316	7,940
Liquid oxygen	Liquid hydrogen	364	–
Fluorine	Liquid hydrogen	373	5,100
Ozone	Liquid hydrogen	380	–

(1) IRFNA is inhibited red fuming nitric acid.
(2) UDETA is 60% unsymmetrical Dimethyl Hydrazine and 40% Diethylene Triamine. It is also known as HYDYNE fuel.

Table 3 compares various fuel/oxidizer combinations for rocket motors. Specific impulse is the pounds of thrust per pound of fuel/oxidizer mixture per second. Values given are for a combustion chamber pressure of 500 psia and exhaust pressures of 1 atmosphere. In practice, higher pressures may be realized, giving a higher I_{sp}. For example, I_{sp} at 500 psi chamber pressure for hydrogen peroxide/gasoline is 248 seconds and the I_{sp} at 1000 psi for this mixture is 273 seconds.

Fundamental laws of chemical thermodynamics show that high flame temperature and low molecular weight of the reaction products are the most important requirements for high specific impulse values. For example, the highest flame temperature system known to be feasible from ordinary molecular reaction is cyanogen and ozone with a combustion temperature of 9467°F. It only has an I_{sp} of 270 however, because of the relatively high molecular weight of the reaction products. The highest rocket performance systems for chemical reaction are, in fact, the system of fluorine[b] and hydrogen, and ozone and hydrogen. Theoretical specific impulse is a rather rough yardstick for assessing propellant performance. Impulse values obtained in practice are actually less than theoretical because at higher temperature levels the reaction products begin to absorb substantial quantities of energy by first dissociating and, eventually, ionizing. Metallurgical advances are also necessary before the potentialities of the high-temperature systems can be realized in rocket combustion chambers.

[b]The Bell Aircraft Corporation has recently succeeded in building a large liquid fluorine engine.

CONCLUSION

In conclusion, it should be pointed out that this paper has presented a necessarily sketchy survey of recent work on aircraft fuels. No reference has been made to nuclear fuels for aircraft propulsion which were considered to be outside the scope of this present survey. At least it has perhaps been possible to show that many developments are taking place to enable fuel quality to keep up with the demands of the aviation industry, not only of today but of tomorrow.

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TEST PILOTS SECTION SYMPOSIUM

RCN AIR STATION SHEARWATER, N.S.

18th and 19th November, 1960

18th November

0900 – Visit to HMCS Bonaventure at sea.

2030 – Dinner at RCN Air Station Shearwater.

Dinner Speaker:

COMMODORE W. M. LANDYMORE, OBE, CD, RCN

19th November

0900 – Session – three papers.

1400 – Open forum.

Open to all members of the C.A.I.

SECONDARY POWER SYSTEMS FOR SPACE VEHICLES†

by S/L D. E. Whyte*

Royal Canadian Air Force

INTRODUCTION

WHETHER man enters space personally or through instrumented satellites, there will be an increasing need for electric power and generation of this power is one of the main obstacles to be overcome before vehicles venture very far into space. The following is a review of the problem as seen by those who are closely associated with it, along with a summary of their views on the systems being considered for space application and their current state of development.

Space imposes severe limitations on power systems which must operate under stringent environmental conditions of temperature, zero gravity and low pressure. Many feel that because of these limitations only static power supplies should be considered, since it will be difficult for rotating equipment to function satisfactorily for long periods of time. Certainly lubrication of equipment, especially reciprocating engines with their many moving parts, would prove difficult. In addition to the environmental limitations, power supplies must have good voltage characteristics with high rate discharge capabilities. They must be lightweight and compact but at the same time be rigid in construction to withstand the stresses of shock and vibration during launching. Singly it is possible to meet these limitations but collectively it is impossible to do so under all circumstances. For instance, batteries are satisfactory for a few hours operation, but to meet the power requirements of Explorer VII for one year would require 550 lb of batteries as compared with the present weight of 33.5 lb for the solar cell-battery system. On the other hand, solar cells are ideal for long term operation, but they are not practical for either large power requirements or for short term operation. Selection of a system, therefore, to meet a particular requirement will depend entirely on the planned mission.

ARDC have made a study of the secondary power requirements of equipment aboard space craft now in the planning stage. Requirements vary from as little as two or three watts for reconnaissance equipment to upwards of 10 kw for manned vehicles. Their detailed breakdown is as follows:

(a) 0-1 kw – instrumented satellites and lunar probes,
(b) 1.6 kw – manned flights around moon, unmanned flight to Mars or Venus with soft landing,
(c) 5 kw – manned space station or stationary Earth satellite,
(d) 10 kw – manned trip to land on moon and return, and
(e) 200 kw – manned space station, 10 men (Lockheed estimate).

When compared with the requirements of the X-15 and DynaSoar, the above values, especially those for manned vehicles, seem to be low. Under glide conditions the X-15 requires approximately 5 kw of electric power and 30 hp of hydraulic power, while peak load requirements for DynaSoar type vehicles are estimated to be 20-200 hp. It is probable, therefore, that the values given are an absolute minimum and that, if anything, they should be revised upwards.

A good deal of study has now been given to the problem of secondary power supplies and many methods of conversion thought to be neither technically feasible nor practical a few years ago are now receiving detailed attention. Important advancements have already been made especially in the field of static and direct conversion, and in many cases working models have been manufactured. Literature on the subject is invariably overly-optimistic, mainly because writers are particularly enthusiastic about systems that they propose. It is our opinion, however, that no particular system has a major lead in any requirement at this time.

Fundamentally there are three basic energy sources, chemical, solar and nuclear (Figure 1). Power systems utilizing these sources can be divided into two categories, those that carry within themselves their own source of

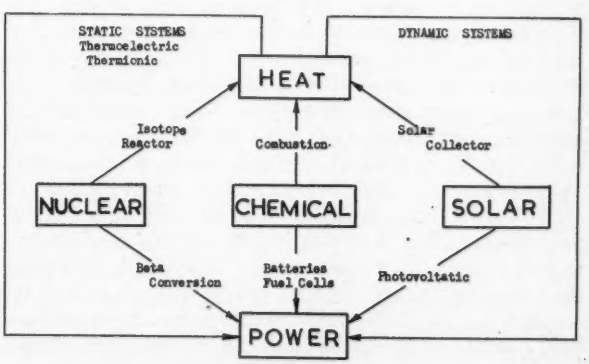

Figure 1
Energy sources and conversion systems

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*Directorate of Instrument and Electrical Engineering.

energy and those that take advantage of energy that may exist in the universe. The first includes chemical and nuclear energy and the second solar and possibly some exotic form of energy peculiar to space. Each of these sources of energy can be converted directly or indirectly into electric power. For instance, solar energy can be converted directly to electric energy through the photovoltaic cell or it can be converted to heat and then to electric energy through a static or dynamic system. In some cases the method of conversion is as important as the source of energy but should not be confused with it. The number of combinations involving these two classifications, including individual components, fluids and methods of arrangement, could number in the hundreds. No attempt will be made to cover all systems and only those that seem to have possible space application will be considered.

SYSTEMS

Mechanical

Although not previously mentioned, mechanical conversion methods, which includes compressed gases, flywheels and springs, are sometimes used for driving generators. Compressed gas in the form of nitrogen was used in some of the early missile systems. This system had the advantage that it could be used during test and then could be readily recharged. However it did not prove too practical from a weight standpoint and has been mainly superceded by battery systems. With the exception of flywheels, the watt-hour/lb rating of mechanical systems is low – 5 for flywheels, 1 for compressed gases and 0.01 for springs. Flywheels might prove attractive for very short flights, because of their simplicity, but in general it can be said that mechanical energy systems are not satisfactory for space applications.

Combustion engine

The essential components of a combustion engine system, sometimes referred to as an Open Cycle System, are the propellant tanks, engine and generator with suitable controls. The hot gases of combustion drive the engine which provides the shaft power to generate electric energy. Either internal combustion (reciprocating) or gas turbine engines may be used, but for space application the latter are superior because of their lighter weight, fewer moving parts and higher speed.

Any of the conventional mono- and bi-propellant liquids and solid propellants may be used as fuel. Each has its advantages and disadvantages so that one cannot be said to be superior for all conditions. Among the known mono-propellants, hydrazine is most attractive. Its ideal specific fuel consumption is 3.4 lb/hp hr. Its drawbacks are that it is toxic as a fluid and that it has a high freezing point of −34°F. Solid propellants are attractive because of simplicity in handling and their reliability. A representative solid such as ammonium oxalate has an ideal specific fuel consumption of 3.7 lb/hp hr, which is slightly greater than that of liquid propellants. Their main drawbacks are that it is difficult to vary the burning rate and, for long duration flights, they are impractical because of the container weights required for the large pressurized volume. Bi-propellants look good for long ranges from the standpoint of energy per unit weight, and studies indicate that the optimum in combustion engine systems is obtained using liquid hydrogen and oxygen. This combination gives a specific fuel consumption of 1.35 lb/hp hr and because liquid hydrogen shows high heat absorption per lb it can be used for vehicle cooling. It is therefore especially adaptable to manned vehicles where power supply functions and environmental control can be combined.

A typical combustion engine system using a mono-propellant is that installed in the X-15 research aircraft. Here two 40 hp units furnish the only power utilized during glide tests. They operate completely independently of the plane's rocket engine and furnish power to keep the pilot alive and to control the aircraft during descent and landing. The units were developed by the General Electric Company and operate on hydrogen peroxide. It decomposes into steam and oxygen to drive a high velocity turbine, producing both electric and hydraulic power. A similar unit developed by AiResearch for missiles (Nike Hercules) uses the mono-propellant ethelyene oxide for fuel but can be modified to use solid propellants with the replacement of about 15% of the parts. Performance figures have not been made available for either of these systems.

Development and operation of a bi-propellant, hydrogen-oxygen engine was recently announced by the Pratt and Whitney Division of United Aircraft Corp. This engine, known as the XLR115, was designed as a propulsion engine and gives 15,000 lb of thrust. Production models are scheduled to push the final stage of multi-stage space rockets, including Centaur and Saturn. This was the first announcement of the successful operation of a cryogenic fuel powered engine, but Vickers Inc. and AiResearch have been working on the development of such engines for generating secondary power in space vehicles. These would be smaller than the one demonstrated by P & W but would be similar in operational characteristics. Preliminary designs indicated that power systems of 10 kva or larger, operating for periods of 10 to 100 hours, are attractive when compared with other systems being planned. These would be suitable to meet the requirements of manned flights to the moon.

There is, of course, another problem to be overcome when considering systems with rotating equipment and that is development of suitable electric generators to operate in a vacuum. The main problem here is cooling and designs must depend on radiation cooling, either directly from the frame to the ultimate heat sink of space or from the generator frame to vehicle skin which radiates to space. The generator showing the greatest promise is the inductor type having no rotating winding, no brushes, capable of withstanding a high temperature environment without cooling and capable of high rotating speeds. General Electric have designed a machine of this type and have proposed it for installation in the B-70 aircraft. This unit employs air bearings.

The advantage of fuel combustion engine systems is that they have now reached a high state of development and have proved their reliability over years of operation. Weights have been optimized and conversion efficiencies are therefore much higher than for known static systems. How successful they are in space application will depend upon the ability of the designer to adopt the present technology of rotating generating equipment to the space environment. Their disadvantage is that they use rotating

components and their weight per unit output increases as the requirement at low power level decreases. For the present, however, they are being counted upon to supply the power needs on space vehicles of medium duration requiring in excess of 0.5 kw of power.

Closed cycle heat engine

In this system a source of energy is used to drive a turbine through a suitable working fluid. The main components are the heat system, boiler, turbine, alternator and condenser. In operation the working fluid is vaporized in the boiler and is supplied to a turbine as a high temperature, high pressure gas. The gas is expanded through the turbine which drives an alternator. The cycle is completed when the gas, at low pressure after passing through the turbine, is cooled and liquified in the condenser.

Any of the main energy sources, that is chemical, nuclear or solar, may be used as a heat source. A study has been carried out on each and the results have been encouraging. For a chemically fueled system which utilizes sulphur as the working fluid and hydrogen and oxygen as the propellant the weight of a 1 hp system on the basis of 300 hours operation was calculated to be less than for the open cycle system. For a solar system the basic weight was slightly more than the closed cycle chemical system but after three hours operation the solar system assumes a weight advantage that becomes progressively larger. Practical considerations, however, limit the application of solar energy until methods are devised for erecting large, parabolic mirrors in space. The mirror for a 20 kw system, for example, must be about 30 ft in diameter. For nuclear systems, using small nuclear reactors with sulphur as the working fluid, the basic weight is calculated to be four times that for the solar or chemical systems without shielding but, like solar systems, fuel weights are negligible.

A working model of a small nuclear system (Snap II) is now in operation in prototype form. This reactor is housed in a cylinder 14 inches diameter and 18 inches high, and weighs 220 lb without shielding. It is fueled with enriched uranium. Heat from the reactor is transferred through liquid sodium coolant to the boiler. Mercury is used as the working fluid and is also used to lubricate the bearings in the power generation system. The turbo-generator weighs 30 lb and generates 3 kw of power. This reactor was developed under AEC's program for development of Systems for Nuclear Auxiliary Power (SNAP) and in its operational form is scheduled to go into operation when activated by a ground signal. It is the smallest known reactor in operation.

Closed cycle systems show promise for future application. On the basis of weight, solar closed cycle systems are expected to replace chemical systems in the 1-20 kw power range, for periods in excess of 10 hours, by 1961. Nuclear closed cycle systems are expected to replace the chemical systems in the 20 kw to 1 mw range, for periods in excess of 5 hours, by 1964.

Battery

In its simplest form a battery system consists of a battery, a rotary or static inverter to supply ac power and a dc motor to drive a hydraulic pump. Both primary and secondary batteries have been utilized in satellites. Primary batteries are suitable where only small amounts of power are required for periods up to a week or so. Secondary batteries, in conjunction with a power supply for recharging purposes, are suitable for longer periods of time.

All Soviet and US satellites to date have utilized either a primary or secondary battery system. Early satellites such as Vanguard I required a 1 watt power supply while Explorer VI had a peak power requirement of 40-50 watts. Both used a battery-solar cell power system and the fact that in these and other US satellites battery performance has been satisfactory attests to their ability to meet conditions of space. Battery systems have many advantages over other power systems in that they convert energy directly, they store energy which is derived not only from chemical reaction but from other sources as well, and they can be packaged to suit almost any space configuration.

Three types each with particular characteristics have been used – these are mercury-zinc, zinc-silver oxide and nickel-cadmium. The zinc-silver oxide battery has a very high discharge capability and at a 10 minute rate will give 30 watt-hours/lb. At a five hour rate this can be increased to approximately 80 watt-hours/lb. In comparison, nickel-cadmium gives 10 watt-hours/lb at the 10 minute rate and about 27 watt-hours/lb at the 5 hour rate. However the nickel-cadmium battery has a much better cycling life than the zinc-silver oxide and is, therefore, more reliable in applications where recharging is planned. The discharge characteristics of the mercury-zinc battery lie between zinc-silver oxide and nickel-cadmium but its low temperature characteristics are very poor. In general mercury-zinc has been used as a primary battery but it may also be used as a secondary battery.

The disadvantage of batteries is that the output is directly proportional to the mass and for large power requirements or for small requirements over long periods of time battery weight becomes excessive. Their future in space vehicles is probably limited to low power application such as is required in short-lived instrumented satellites or when used in conjunction with charging facilities for peak loads and dark periods. Improvements in battery systems could broaden their application somewhat but it is not expected that they will prove attractive as a prime power source if more than 100 watts are required for periods in excess of 10 hours.

Fuel cell

In operation, a fuel cell is similar to a battery so that the basic components of a fuel cell system would be the same as for a battery system. The difference between them is purely physical; in a conventional cell the energy is stored internally in the plates and in a fuel cell it is stored externally in separate containers. For instance, the hydrogen-oxygen cell consists of two porous electrodes in an electrolyte solution of potassium hydroxide plus separate containers of oxygen and hydrogen.

In operation oxygen is supplied to the positive electrode and hydrogen to the negative. The two gases come into contact with the electrolyte through the porous electrodes, and the chemical energy of recombination is converted directly to electrical form. The output consists of electrical energy and water and the reaction continues as long as the supply of oxygen and hydrogen is main-

tained. There are a number of systems similar to the hydrogen-oxygen system, but in theory it offers more advantages for space application than the others and most of the development work in the USA has been on this cell. ARDC studies indicate that the best approach is to use liquid oxygen and hydrogen. The theoretical outputs of such a system vary from 105 to 815 watt-hours/lb depending upon the duration of the mission. This is considerably in excess of the outputs that can be obtained from the best battery systems.

The earliest development work on hydrogen-oxygen cells is attributed to National Research and Development Corporation of Great Britain (Bacon Cell) closely followed by National Carbon Co. of the USA. The former has operated one cell continuously for 1500 hours and the latter one intermittently for 2 years. The main difference between the two developments is that the Bacon Cell operates at elevated temperatures of 240°C, while the other operates at room temperature. Another development recently announced by General Electric was a variation of the hydrogen-oxygen cell called an ion exchange cell. The difference between it and the conventional hydrogen-oxygen cell is that a membrane replaces the electrolyte. A 100 watt unit has been in operation for months and a 170 watt unit is scheduled for delivery to the US Navy in 1960. The first practical application of a fuel cell was made by Allis-Chalmers Co. in November 1959 when they used a propane-oxygen cell to power a 20 hp tractor. The unit is said to be comparable in size to an equivalent gasoline engine but officials feel that the size could easily be halved immediately. Several other firms both in the USA and Europe have made notable strides in the development of cells but as yet all are strictly in the development stage.

Fuel cell systems offer many of the advantages of normal battery systems and probably with further development will be superior to them. The necessity of carrying all the fuel needed for an entire mission could be overcome by using solar or nuclear energy to convert water back into hydrogen and oxygen in a closed cycle. Efficiencies are estimated to be high but any predictions as to their over-all capability and reliability would be premature in their present state of development. Their most probable application in space vehicles would be to replace batteries.

Solar cell

The components of a solar cell system would be the same as for a battery system except that the solar cell would replace the battery. To date, when solar cells have been used it has been as a modified system using solar cells as the primary power source along with a rechargeable battery as a secondary power source. This is the system that will invariably be used for space applications because it allows the designer to meet average rather than peak loads and ensures a source of power even when the satellite is in shadow.

The photovoltaic principle on which cells operate was first discovered 130 years ago but was not used until recently, except in such devices as light meters, because of low conversion efficiencies. A major breakthrough in this area was achieved by Bell Telephone Laboratories in 1954 with the development of the single crystal P-N silicon type cell. This cell, which is now called the solar cell, is a thin wafer of silicon 0.5 mm in thickness into which has been diffused the element boron. The boron diffusion takes place in the surface and is about 1 micron in thickness. In this region the N type silicon is converted to P type silicon so that when the cell is exposed to light a voltage is developed between the P and N type junction.

A typical cell when exposed to full sunlight develops about 0.35 volts at an output of 13 watts/sq ft. The total solar energy available at a point directly above the earth's atmosphere is 130 watts/sq ft so that conversion efficiency is now about 10%. This represents an increase in efficiency of about 10 times over that which could be obtained prior to the development of the silicon cell. In an integrated system which is unoriented this value of efficiency would be reduced to about 2% and if the installation was in a satellite orbiting the earth the efficiency would be still further reduced by another 40% to allow for time while the satellite is in the earth's shadow.

The first practical application of the silicon solar cell was made in the Vanguard I satellite where the secondary power source was a mercury oxide battery. Subsequent installations with nickel-cadmium batteries were made in both Explorer VI and Explorer VII satellites. In Explorer VI 8000 cells were used, mounted 1000 on each side of four paddlewheels. The output was rated at 30 watts but subsequent information has disclosed that the output was slightly less than expected. In Explorer VII the cells were designed to fit into the top-like satellite structure in the form of two truncated cones. Each cone weighed 8.75 lb and the total weight including the battery was 33.5 lb. The output of this unit was 5 watts. Based on an operating cycle of 60% on and 40% off for each orbit, this system gives 800 watt-hours/lb when calculated over the period of one year.

The solar cell system has many advantages and disadvantages. The chief advantages are that for low power requirements it has a low fixed weight and there is no fuel to be carried. Being static it is reliable. There is no heat to dissipate and theoretically it can operate for indefinite periods. The disadvantages are that only very small cells can be produced (2 sq cm) because no method has been perfected for growing large single crystals. Systems therefore require a large number of cells which must be carefully selected for matching qualities. This and the fact that a large number of cells must be assembled in a series-parallel arrangement makes the initial cost high. This cost is increased by six when systems are unoriented and, if oriented, the control mechanism becomes a problem. Solar cells systems are limited in operation to areas within the solar system because the available energy decreases with distance from the sun.

In space applications, the system in its present state of development is superior to other systems when capacity requirements do not exceed 500 watts and the length of time required is in excess of a couple of days. Actually the longer a solar cell is utilized the more practical it becomes because it requires no increase in initial weight to increase the life. Development of the solar cell system is really in its infancy and already a great deal of effort is being expended toward improvements. A number of new materials are now being tested,

including gallium arsenide, gallium phosphide, indium phosphide, cadmium telluride and cadmium phosphide. RCA recently demonstrated a gallium arsenide cell which was reported to be capable of higher efficiencies than the present silicon cell. A further suggested improvement in cells would be the development of a cell using a combination of materials that could operate over a broader range of the solar spectrum. Efficiencies of 35% are predicted for such a cell. Still another suggestion for increasing system capabilities is the development of a large sheet of cells that could be folded for launch and unfurled in space. Despite any probable improvements that might well extend cell capabilities, it is expected that the principal use of solar cell systems will continue to be in instrumented satellites.

Thermoelectric

Basically thermoelectricity is the conversion of heat energy directly to electric energy through a thermoelectric generator. The principle of the generator is simple; if the junctions of two dissimilar metals in a closed circuit are at different temperatures a current will be generated. The principle has long been applied in temperature control and measuring devices, such as thermocouples, but it has never been used on this continent as a method for generating power. Recent development in semiconductor devices has, however, led to a renewed interest in this field and considerable research work is now in progress on thermoelectric generation.

Russia has been given the credit of being the first to make practical application of thermoelectricity, which they are using extensively in remote northern regions. A sample of one of their generators, which is used to power small radios, was recently purchased by NRC. It consists of a thermopile built around the chimney of an ordinary kerosene lamp. The junctions are zinc antimonide. The ouput is about 2 watts but varies somewhat in accordance with the wick adjustment. The basic weight of the generator is 11 lb and fuel consumption is 90 grams/hr which gives a specific fuel consumption of 75 lb/hp hr. It is reported that several hundred units of 15 kw capacity are now in use in Russia.

Demonstration of Snap III before President Eisenhower in January, 1959, was the first evidence that practical power generation by thermoelectric means had been accomplished in the USA. The device was an experimental nuclear powered, thermoelectric generator using the radiosotope Polonium 210 as the energy source. It was manufactured by Minnesota Mining and Manufacturing Co. and was made up of 27 pairs of lead telluride couples (rods) arranged radially around the metal fuel source container. The cold junctions terminated in an aluminium ring but were electrically insulated from it by a plastic material with good heat transfer characteristics. The output was 2.5 watts with the hot juction operating at a temperature of 1100°F and the cold junction at 400°F. Based on an operating life of 138 days (half life of polonium) and a weight of 5 lb, this corresponds to 0.50 lb/hp hr. While the generator was designed as a proof of the principle of this device, officials were quite satisfied that the results indicated that the joining of thermoelectricity and nuclear energy was practical and that, with minor design changes and a few material substitutions, the present weight could be reduced by over 50%.

In other development, sponsored by ARDC, Westinghouse has produced a 100 watt unit which uses gas for fuel and is reported to have an efficiency of 8%. The thermoelectric material is a combination of semiconductors in cascade developed by Westinghouse. An advanced version of this will use a nuclear isotope for fuel. Another scheme under consideration involves the use of a solar mirror or concentrator as the heat source, and a 2 watt experimental model of this type was demonstrated by Westinghouse at the AIEE Conference held in Seattle in June, 1959.

The future of thermoelectric devices for space application is difficult to predict because the potentialities are just beginning to be explored. The interest shown in the USA in development is evidenced by the fact that 837 firms were engaged in thermoelectric research and development in 1959. In this program moneys have been allocated roughly on the following basis: materials 50%, devices 40%, generators and radiators 7%, controls 2% and services 1%. The attention given materials is of course important but all other aspects of the problem must be considered in designing a workable system. As yet the specific weights of thermoelectric generators are about 1.2 lb/watt but the next couple of years should yield significant improvements in this respect. At the moment, however, nothing indicates that thermoelectric conversion will replace dynamic conversion except maybe for small power requirements.

Thermionic

Thermionic systems are similar to thermoelectric systems except that a thermionic generator replaces the P-N junctions. A thermionic generator is a high temperature (5000°F) heat engine consisting of a hot electron-emitting surface (cathode) and a cold collector (anode) electrically insulated from each other and surrounded by a vacuum. In some cases special gases are used in lieu of the vacuum. Heat applied to the cathode releases electrons and causes a current to flow in a closed circuit. Typical materials for the cathode and anode are tungsten ribbon and nickel.

Experimental models of a generator have been built and tested by RCA in conjunction with Thiokel Chemical Corp. These generators, in the form of hollow cylinders 12 inches long and 1.75 inches in diameter, fit over the flame tubes of small solid propellant test engines. Of the first ten tested nine operated satisfactorily. Generators in their present stage of development weigh 3.5 lb and give about 270 watts output. Officials believe that 150-175 watts/lb will eventually be obtained, corresponding to an efficiency of 35%. In addition to the solid propellant units already tested, designs have been completed for use of liquid propellant engines. Later it is planned to design generators for continuous operation using both solar and nuclear energy sources.

The chief advantages of thermionic generators are that they are static and simple. Their possible application in space vehicles would be similar to the thermoelectric generator, but a great deal of development work remains to be done before any practical applications can be considered. The present figures being quoted for system weights vary considerably and of course are dependent

upon the energy source. For solar it is about 0.2 lb/watt which is considerably less than for thermoelectric system.

Nuclear energy

Two nuclear sources which show promise of yielding electric power in quantities suitable for space vehicles are radioisotopes and nuclear fission. The energy from radioisotopes may be converted directly to electrical energy through nuclear batteries or indirectly through thermoelectric generators, such as in Snap III already mentioned. The energy from fissionable materials is obtained indirectly by first changing to heat through a reactor and then converting to electrical energy by suitable means, such as the closed cycle engine system used in Snap II.

Strontium nuclear batteries are an example of direct conversion. Strontium 90 has a half life of 10 years and batteries have operated for almost that length of time with satisfactory results. Models of krypton 85 and tritium batteries have been constructed and tested. They all differ somewhat in details but depend on beta emission for their operation. Their chief characteristics are high voltage and low current (micro-microamperes), so for other than special projects they are of little value. Sometime ago Radiation Research Corp. proposed a design for a 1 kw battery using cerium 144 which was designed to operate at high altitudes only. No information is available to indicate that the suggestion ever got past the proposal stage.

In using radioisotopes for indirect conversion there are specific applications where they are seriously limited. These limitations are due to the size and the weight of the shielding necessary to control harmful radiation. In such cases the answer lies in the use of alpha emitters as the heat source. Three isotopes that have merit are: curium 242, half life 162 days; polonium 210, half life 138 days; and plutonium 238, half life 86.4 years. The first two are in the short life, high power category, and plutonium will answer the problem of long lived heat source. The lower limit of power for such systems is considered to be 1 watt and the upper limit 1 kw.

For large capacity nuclear systems, fission reactors will have to be used. They are as yet very much in the development stage although Snap II, previously referred to, is now in operation. The main problems are heat dispersal and shielding. A study on a 1 mw unit for 400 days operation has been carried out by GE scientists. Basically the power package is a closed cycle system using helium gas heated to 2140°F as the working fluid. The gas drives a 12-stage turbine which in turn drives a compressor and a 1 mw induction alternator. After the helium has been expanded through the turbine it is passed through a 16,800 sq ft radiator where it is cooled to 215°F. The radiator dissipates 6.8 mw of power for an over-all system efficiency of 16%. Such units should be a reality about 1965.

Nuclear systems show many advantages but they have yet to prove themselves. They are compact and promise excellent weight to power ratios as well as lower costs at higher outputs. They operate independent of environment and although they have a time limitation they can be designed to operate for a number of years. They operate continuously, so no storage facilities are required

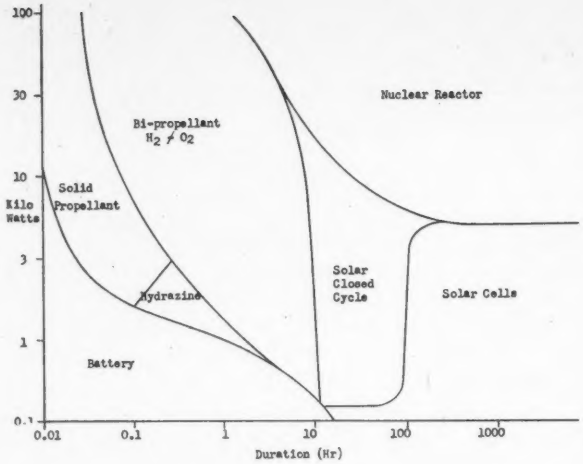

Figure 2
Optimum weight areas for spacecraft APU systems

for electrical energy, and they are readily adaptable to either static or dynamic conversion. Their main disadvantage is that they give off harmful radiation which could prove hazardous on re-entry or on aborted take-offs. In this respect radioisotopes are more dangerous than reactors. A limitating factor too in isotope systems is that there will probably never be enough for large scale use.

CONCLUSION

A comparison of the various systems discussed from the point of view of weight is presented in graphical form in Figure 2. Thermoelectric and thermionic systems are not included because there is no concrete data on which to base accurate calculations. Where solar cells are shown to be optimum, calculations are based on the energy level pertaining in the region of the earth. These values would not apply for long duration trips beyond our solar regions. Performance figures for some of the systems are, of course, based on calculations rather than on performance and are therefore dependent upon future developments, and subject to change.

For the present, low power requirements will be satisfied by solar cell-battery systems and for loads of 1 kw or more fuel combustion systems will be required. Development of both solar and nuclear power systems of large capacities are required for future long term space explorations.

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C.A.I. LOG

SECRETARY'S LETTER

SPECIALIST SECTIONS

DURING a recent visit to Montreal I had a meeting with W/C Londeau and Mr. Kidd, the Secretaries of the Propulsion and Test Pilots Sections respectively, and we had an interesting conversation about Section matters in general. The Sections, after a year or two of sedimentation, in which a few impracticable ideas have settled to the bottom, are now ready to render a useful service; I think that their primary activity will be the holding of specialist symposia on a national scale and discussion evenings on a local or Group scale. (A Group comprises the members of a Section living in one area.) The Astronautics Section has organized a very impressive programme for its Canadian High Altitude Research Symposium, to be held in Ottawa on the 20th and 21st October; and the Test Pilots Section will also hold a Symposium at the Halifax-Dartmouth Branch on the 18th and 19th November. I understand that the Propulsion Section will hold a rather less ambitious meeting, which is more in the nature of a discussion evening or perhaps Group symposium, in Montreal in early November.

Section and Group meetings are open to all members of the CAI but each Section confers certain privileges on its own members which are not available to the membership at large. For example, a limited number of copies of the publications of the (American) Society of Experimental Test Pilots have been made available at half price to the members of the CAI Test Pilots Section. Members of the Institute should join the Sections for which they possess the necessary qualifications. There are no additional dues for Section membership, but no one can belong to a Section without first being a member of the Institute.

To become a member of a Section and to be put on its mailing list, it is necessary to apply on a special form. There is one inserted, loose, in this issue of the Journal, with the so-called "Identifying Qualifications" for the three Sections printed on the back.

McCURDY AWARD

In the last issue and again on page 308 of this one, we are inviting nominations for the McCurdy Award. I believe that there are some misconceptions about this Award and I should like to say a few words about it.

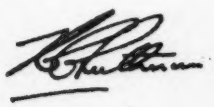
The past winners of the Award have all been people who have done outstanding jobs and, except that they should have done them in Canada, there was no other requirement. The fact that the winners have usually been in senior positions was coincidental. The Award is given for doing an outstanding job, be it in the technical organization of a major project or in a salvage operation of unusual difficulty or in improvisation in some bush operation or, in fact, in doing any bread-and-butter job superlatively well. It is *not* reserved for the "top brass", as some people think.

I hope that this year we shall get more nominations of less senior people. The Senior Awards Committee will judge as fairly as humanly possible between the widely differing achievements of the nominees, to select the most worthy of recognition; the significance of the contribution, the effort put into it, the difficulties overcome and many other factors will all be given due weight. The only requirement for any nomination is that the achievement for which the nomination is being made should be, in its own way, a "bloody good show".

NATIONAL AVIATION MUSEUM

It is expected that the National Aviation Museum, housed for the next few years in the new terminal building at Ottawa Airport, will be formally opened on the 25th of this month. I can strongly recommend a visit. The Curator is Mr. K. M. Molson, who used to be one of our more active members in Toronto, and I am sure he will be very glad to meet CAI visitors.

One word of warning. The RCAF model of the Silver Dart is readily visible in the hall downstairs, but don't be misled into thinking that this is all; the Museum proper is upstairs, in the east wing of the building. It is well worth the short climb.



JOINT I.A.S./C.A.I. MEETING

The Queen Elizabeth, Montreal

October 17th Morning 9.00 a.m.

MANUFACTURE AND TESTING

Chairman

J. W. AMES
Vice-President and General Manager,
Canadian Applied Research Limited

Some Techniques Used for the Ground Resonant Testing of Aircraft

C. E. TAMMADGE
Senior Engineer, Dynamic Test Group, Canadair Ltd.

Development and Checkout of the NASA Mercury Capsule

G. B. NORTH
Project Crew Station Engineer, McDonnell Aircraft Corp.

Manufacture and Testing of Black Brant Engines

I. R. CAMERON
Superintendent, Propulsion Wing, CARDE

October 17th Afternoon 2.00 p.m.

TELECOMMUNICATIONS

Chairman

I. M. LISS
Litton Systems Ltd.

Long Range Communication with Aircraft

DR. J. H. MEEK
Superintendent, Communications Laboratory, DRTE

The Development of a Global Communications Satellite System

DR. A. M. LEVINE
Vice-President, ITT Laboratories

Problems of Interplanetary Communication: Solar Orbiting Satellites

R. SMELT
Chief Scientist, Missiles and Space Division,
Lockheed Aircraft Corp.

October 17th Evening 7.00 p.m.

DINNER

Chairman

DAVID BOYD
President, Canadian Aeronautical Institute

Principal Speaker

F. R. THURSTON
Director, National Aeronautical Establishment

October 18th Morning 9.00 a.m.

AERODYNAMICS

Chairman

R. J. TEMPLIN
Head, Aerodynamics Section,
National Aeronautical Establishment

Design of an Inlet Duct for a Propeller-Turbine on an STOL Aircraft

DR. D. H. HENSHAW
Aerodynamicist, The De Havilland Aircraft of Canada Ltd.

The BLC Hercules – A Practical STOL Transport

F. N. DICKERMAN
Assistant Chief Engineer, and

C. F. BRANSON
Aircraft Development Engineer Specialist,
Georgia Division, Lockheed Aircraft Corp.

Aerodynamics of Blasts

PROF. I. I. GLASS
Prof. of Aeronautical Engineering, Institute of Aerophysics,
University of Toronto

October 18th Afternoon 2.00 p.m.

POWER PLANTS AND PROPULSION

Chairman

PROF. D. L. MORDELL
Dean, Faculty of Engineering, McGill University

An Air-breathing Satellite Booster

S. MOLDER AND PROF. J. H. T. WU
Hypersonics Group, McGill University

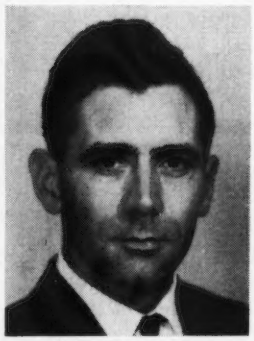
Aerodynamics of the PT-6 Gas Path

J. C. VRANA
Combustion Engineer,
Canadian Pratt & Whitney Aircraft Company Ltd.

Non-Propulsive Power Systems for Long-Time Space Application

B. LUBARSKY AND R. E. ENGLISH
Lewis Research Center, NASA

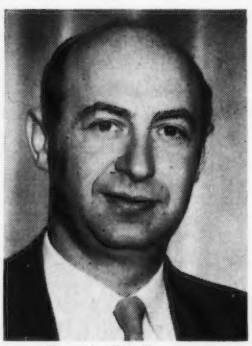
THE SPEAKERS


C. E. Tammadge

G. B. North

I. R. Cameron

Dr. J. H. Meek


Dr. A. M. Levine

R. Smelt

Dr. D. H. Henshaw

F. N. Dickerman

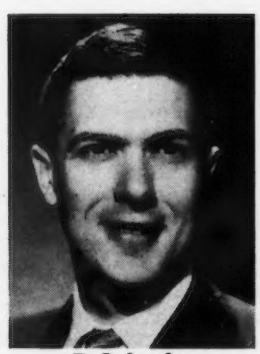
C. F. Branson

Dr. I. I. Glass

S. Molder

Prof. J. H. T. Wu

J. C. Vrana


B. Lubarsky

R. E. English

JOINT I.A.S./C.A.I. MEETING

JOINT I.A.S./C.A.I. MEETING

Notices giving the full programme of the Joint IAS/CAI Meeting have been sent to all members of the Institute; the programme is also set out on the preceding pages.

ABSTRACTS

The following are abstracts of the papers to be presented at the Joint IAS/CAI Meeting.

Some Techniques Used for the Ground Resonant Testing of Aircraft

C. E. Tammadge – Canadair

Modern methods of ground resonant testing of aircraft require elaborate techniques and equipment, which have resulted in an undesirable increase in the testing time. To counteract this time increase, specialized equipment has been developed. This paper contains details of the testing techniques and equipment used at Canadair for the determination of the natural frequencies and mode shapes of small and large aircraft. It includes the use of a large number of fixed transducers to measure the structural mode shapes, a semi-automatic polar recorder for plotting vector diagrams and the use of computing machines for the rapid reduction of test data.

Development and Checkout of the NASA Mercury Capsule

G. B. North – McDonnell

General Capsule and Mission Description

Description of capsule and escape tower assembly. Location of capsule systems.
Description of mission sequences and parameters.

Development and Qualification Tests

Qualification of subcontracted components.
Wind tunnel tests.
Drop tests of capsule, dummy pilot and pigs.
Explosive hatch and clamp ring tests.
Communication capsule tests.
Altitude chamber tests of environmental control system.
Crew station evaluation with pressure suit in mock-up and analog simulator.
Centrifuge tests of couch and restraint.
Pilot egress tests at MAC, Langley and Pensacola.
Parachute tests at Salton Sea.
Off-the-pad escape at Wallops Island.
Big Joe Launch at Cape Canaveral.

Capsule Checkout

Capsule system tests at McDonnell, including vibration, altitude chamber and ASCS fixture tests.
Capsule preparation at Cape Canaveral.
Description of operational plan.
Hangar procedures.
Launching pad procedures.

General Status of Project Mercury

Manufacture and Testing of Black Brant Engines

I. R. Cameron – CARDE

The Canadian rocket propulsion programme has been an integrated programme including ingredient development, process engineering, rocket engine static testing and flight evaluation of test vehicles. Several synthetic elastomeric polymers have been developed and evaluated in various size engines. A remotely controlled, oxidizer grinding and handling system has been engineered and installed. A unique mixing and casting system has been devised and is in use; casting pots have been eliminated by this system which is also remotely operated. Facilities for temperature conditioning and statically firing large solid rocket engines have been built at CARDE and a fixed azimuth inclined launcher has been installed at Fort Churchill. Several 17 inch diameter Black Brant vehicles have been fired from this launcher with very satisfactory engine and vehicle performance.

Long Range Communication with Aircraft

Dr. J. H. Meek – DRTE

Beyond the horizon radio communication with aircraft is made difficult due to the varying range from the ground station. The various modes of propagation which are encountered will be mentioned. There will be some discussion of ways of improvement and maintenance of such communications circuits.

The Development of a Global Communications Satellite System

Dr. A. M. Levine – ITT Labs

The development problems of a 24-hour communication satellite system, and the system requirements and design approach for an experimental satellite to prove the feasibility and be a first step in the over-all development of such a system are presented. Although the complete system problem is briefly considered, that is, from launch to final operational status in the 24-hour orbit, primary emphasis is placed upon the satellite once it is placed into the 24-hour orbit and the ground environment (communication and guidance subsystems) associated with the satellite at that time. The critical system requirements and principal development problems are summarized for the primary subsystems; namely, the communication subsystem, guidance and control subsystem, power supply, and vehicle subsystem. The communication satellite described is based upon the present state-of-the-art in the fields of communications, guidance and control, and rocketry to substantiate the feasibility of such an experimental satellite relay station in the near future.

Problems of Interplanetary Communication: Solar Orbiting Satellites

R. Smelt – Lockheed

After a brief examination of the communication techniques now in use on the first generation of space vehicles, the developments required to extend these techniques to the longer ranges of lunar and interplanetary flight are discussed. The nature of most of these developments is evident from a study of the simple radio range relation; increases in antenna size and transmitter power, improvements in detector sensitivity, economy in band width and choice of optimum frequency and modulation system, are all indicated as desirable from this simple relation. A review of these factors, however, indicates that they have implications in the design of the space vehicle itself, and upon the flexibility of operation which can be obtained. It follows that for many of these factors an optimum selection can be made, based upon the economics of the complete vehicle and communication system.

The paper contains a brief discussion of the space station as an aid to space communications. The properties of satellite and planetary orbits are such that there are a number of special configurations which may be of some utility in establishing an intermediate station for communication links throughout space.

Design of an Inlet Duct for a Propeller-Turbine on an STOL Aircraft

Dr. D. H. Henshaw – DHC

The De Havilland Aircraft of Canada is currently designing a propeller-turbine

installation for the STOL Caribou. Special inlet-duct design considerations have been encountered because of the necessity of adopting an S-shaped duct which passes around the power shaft of the GE T64 engine.

Turbine inlet ducts have a strong influence on aircraft performance, particularly for the STOL takeoff and climb manœuvres. Accordingly, detailed studies were made to assure that the maximum aircraft performance would be achieved.

Studies were made using both 2- and 3-dimensional, electrolytic analogy tanks to establish the potential flow characteristics of the duct. These results were then applied to the design of an actual duct which was tested on the engine.

The electrolytic tank studies proved useful for establishing the relative importance of various duct design parameters and so allowed a high performance duct design to be established with a minimum of time and expense.

The BLC Hercules – A Practical STOL Transport

F. N. Dickerman and C. F. Branson – Lockheed

The Georgia Division of Lockheed Aircraft Corporation has built and flown a C-130 Hercules airplane incorporating blowing boundary layer control applied to the wing flaps and all control surfaces.

The history of this development is traced from its inception up to the present time. It covers the selection of the type of boundary layer control employed, extensive wind tunnel testing to confirm and develop the selected configuration, a description of the hardware and a comparison of the flight test results with estimated data.

The prototype has fully confirmed the feasibility of achieving STOL capability in a large cargo transport such as the C-130.

Aerodynamics of Blasts

Dr. I. I. Glass – UTIA

For the past decade theoretical and experimental investigations have been conducted at the Institute of Aerophysics on shock-tube flows. Recently, this work was extended to include the analogous flows generated by spherical and cylindrical explosions. Glass spheres and cylinders are pressurized by means of compressed gases or combustible mixtures and are shattered to generate an explosion. Similar methods can be used for implosions, underwater explosions and wave interactions. The finite mass, strength and breaking time of the glass diaphragms impose some limitations on certain experiments where this technique is used to generate a blast wave. Nevertheless, the method has proved very valuable in the study of many basic properties of spherical and cylindrical blast phenomena that have been investigated using piezo-pressure gauges and several schlieren and shadowgraph techniques. Some consideration is given to intense explosions from concentrated energy sources for spherical, cylindrical and planar blasts, and explosions and implosions generated from finite sources with the same geometries. Blast-wave simulators for aerodynamic tests and the dynamic testing of structural components are briefly discussed.

An Air-breathing Satellite Booster

S. Molder and Prof. J. H. T. Wu – McGill

A three stage composite earth satellite launching system has been studied. The first stage, consisting of a jettisonable rocket cluster, provides power for takeoff, initial climb to 40,000 ft and acceleration to the second stage ramjet starting velocity of 1,000 ft/sec. Two trajectories of the second stage (a recoverable, ramjet powered, lifting vehicle) have been computed on an IBM 650 Digital Computer. The initial conditions of the two trajectories are the same except that for one the lift-drag ratio is 6.0, and for the other it is 3.0. The third stage is a rocket which takes its payload to orbital conditions.

The work of this report is devoted mainly to the performance of the second (ramjet) stage. Ramjet performance analysis brings out an important parameter quite similar to wing loading; it is here called the intake loading and is found by dividing the weight of the ramjet vehicle by the intake area (W/A). It is shown that W/A is a scaling factor for ramjet performance.

The calculations show that it is possible to boost into orbit a payload which is 3.25% of the initial all-up weight.

Aerodynamics of the PT6 Gas Path

J. C. Vrana – C P & W

The factors leading to the selection of a free turbine, opposed shaft engine configuration are briefly reviewed. The aerodynamics of the intake, burner and exhaust sections are then discussed and reference is made to a single stream-tube method for rough analysis of axisymmetric flows. A brief film showing water tunnel flow patterns for the burner will be shown.

Non-Propulsive Power Systems for Long-Time Space Applications

B. Lubarsky and R. E. English – NASA

The long-time, non-propulsive, electric power requirements of the NASA space flight program and the systems currently being contemplated to meet these requirements are discussed. These flights generally require a power of less than 1 kw but some could require 1 to 100 kw.

Solar photocell systems are most likely to provide this power in the sub-kilowatt range; thermoelectric systems are useful for special applications. Above a few kilowatts, the turbogenerator system is most prominent. Thermionic emitters and fuel cells are potentially useful devices still in the laboratory.

COMING EVENTS

SAE

9th-13th January, 1961 — *International Congress and Exposition of Automotive Engineering*, DETROIT, MICHIGAN.

CAI

27th-28th February, 1961 — *Mid-season Meeting*, WINNIPEG, MAN.

ASQC

Montreal Section

22nd October — *Fourth Annual All-Day Quality Control Forum*, ECOLE POLYTECHNIQUE, MONTREAL, P.Q.

SECTIONS

Test Pilots

18th-19th November — *Symposium*, RCN AIR STN. SHEARWATER, DARTMOUTH, N.S.

BRANCHES

Tour Speaker

A Review of Technical Requirements for the Operation of Aircraft at Sea, CDR J. F. FRANK.

14th November – Vancouver
15th November – Calgary
16th November – Edmonton
17th November – Cold Lake
18th November – Winnipeg

CANADIAN HIGH ALTITUDE RESEARCH SYMPOSIUM

Sponsored by the Astronautics Section of the CAI

Chateau Laurier, Ottawa

20th October Morning 9.00 a.m.

Chairman

DR. P. M. MILLMAN
National Research Council
Chairman, Astronautics Section, CAI

Some Canadian Space Science Objectives

DR. D. C. ROSE
Chairman, Associate Committee on Space Research, National Research Council

The C.A.R.D.E. Upper Atmosphere Research Program

R. F. CHINNICK
Superintendent, Electronics Wing, CARDE

Design and Selection of Solid Propellant Rockets for Aerospace Research

L. A. DICKINSON
Head, Rocket Engine Development Section, and
F. JACKSON
Ballistics Group, CARDE

20th October Afternoon 2.00 p.m.

Chairman

D. BOGDANOFF
Canadair Limited
Past Chairman, Astronautics Section, CAI

Experiments in Chemically Seeding the Upper Atmosphere by Rockets

F. R. PARK
Senior Research Officer, Radio and Electrical Engineering Division, National Research Council

The Measurement of Major Atmospheric Constituent Concentrations in the 100 km Region by a Chemical Seeding Technique

G. B. SPINDLER
Project Coordinator of the Upper Atmospheric Composition Studies Program, CARDE

Techniques for the Measurement of the Thermodynamic Properties of the Upper Atmosphere

DR. G. N. PATTERSON
Director, and
DR. J. H. DELEEUW
Institute of Aerophysics, University of Toronto

21st October Morning 9.00 a.m.

Chairman

PROF. G. S. GLINSKI
University of Ottawa
Vice-Chairman, Astronautics Section, CAI

Rocket Studies of Ionosphere Absorption

DR. W. J. HEIKKILA
Head, Rocket Section, and
DR. A. W. ADEY, S. R. PENSTONE AND W. K. LACEY
Research Scientists, Rocket Section, DRTE

Measurements of Charged Particles above the Atmosphere

DR. I. B. MCDIARMID
Associate Research Officer, National Research Council

A Falling Sphere Electron Density Experiment

PROF. P. A. FORSYTH AND A. KAVADAS
Institute of Upper Atmospheric Physics, University of Saskatchewan

The Use of Artificial Satellites and Rockets in the Study of Meteoritic Bodies

DR. P. M. MILLMAN
Head, Upper Atmosphere Research, National Research Council

21st October Afternoon 2.00 p.m.

Chairman

DR. J. J. GREEN
Defence Research Board

General Discussion led by the following Panel

MR. D. BOGDANOFF, Canadair Limited

DR. G. V. BULL, CARDE

DR. J. H. CHAPMAN, DRTE

PROF. P. A. FORSYTH, University of Saskatchewan

BRANCHES

APPOINTMENTS

Montreal

Mr. C. R. Bernier has been appointed Treasurer of the Branch on the resignation of Mr. W. C. Rhodes who has left for the United States.

Cold Lake

W/C I. S. McLeish has been appointed Vice-Chairman on the transfer of F/L A. Anderson.

NEWS

Quebec

Reported by Prof. C. H. I. Nicholl

June Meeting

The second technical meeting of the Quebec Branch of the CAI was held on the 21st June in the Engineering Building of Laval University.

Dr. G. V. Bull of CARDE introduced the speaker, Mr. R. J. Templin of the National Aeronautical Establishment, who gave the assembled members and their guests a most interesting and well illustrated talk on "VTOL – STOL Research Activity in Canada".

The Aerodynamics Section of NAE, of which Mr. Templin is Head, has been particularly active during the past few years in promoting interest in the problems of flight at very low speeds; and it must have been gratifying for him to be able to speak of a number of worthwhile projects now under way.

Among the most interesting company projects which he discussed were the De Havilland Otter test rig and the Canadair prototype CL-84 tilt-wing aircraft. We are grateful to Canadair for releasing to him the very striking photographs of this aeroplane which he showed us.

Nearly all of the fundamental research under way in Canada at the present time is being carried out in the laboratories of the NAE in Ottawa. Several vehicle-borne test rigs have been developed, and the vertical tunnel formerly used for spinning tests is being provided with the necessary auxiliary equipment for the testing of VTOL models. NAE has concentrated its investigations so far on the problems of propellers at high angles of attack, slipstream deflection, submerged fans, thrust augmentation and the other difficulties associated with the propulsive system at very low forward speeds.

Finally, the speaker mentioned the work on the deflection of jet curtains and the ground effect phenomenon at the University of Toronto, and the study of boundary layer control at high C_L utilizing Coanda effect under way at Laval University. The Defence Research Board is supporting these investigations.

The speaker was thanked by Mr. F. Jackson, and the questions raised by the audience indicated a lively interest in his topic.

Vancouver

Reported by M. G. Brechin

September Meeting

On Wednesday, September 15th, the first regular meeting of the 1960-61 season was held at the RCAF Officers' Mess, Sea Island, Vancouver Airport, B.C., and was attended by 38 members and 10 guests.

The Chairman, Mr. F. L. Hartley, called the meeting to order at 8.15 pm. Two new members were introduced as were the 10 guests attending.

W/C T. J. MacKinnon, Commanding Officer of the Sea Island station, who replaced W/C J. V. Watts, was introduced by the Chairman. W/C MacKinnon welcomed the membership of the Vancouver Branch to the RCAF Station and specifically to the Officers' Mess. He also expressed a keen interest in the CAI and its activities here and in other parts of Canada, as well as the cordial relationship between the CAI and the RCAF.

Mr. Hartley, on behalf of the Vancouver Branch membership, thanked W/C MacKinnon for his kind welcome and expressed our appreciation to the RCAF for use of their facilities.

Mr. R. J. McWilliams has been appointed Acting Past Chairman to replace Mr. J. R. S. Hutton who has been transferred to Montreal. Mr. McWilliams was given a vote of thanks for his continued and valued assistance.

Apologies were offered by the Chairman for the cancellation of the 1959-60 Spring Wind-up, which had been scheduled as a visit to Patricia Bay for a get-together with the Royal Roads student body and a visit to see the Mars-Water Bomber.

The Executive has held a number of regular meetings and one special meeting on student activities during the summer to handle the normal Branch business and to plan the 1960-61 program.

A review of the membership and student activity was given by Mr. S. C. Ward, Membership Chairman, who noted a decline in the Student membership at the University of British Columbia due to the limited number of students taking the aeronautical course. The CAI Student membership at the Canadian Services College, Royal Roads, continues to include over one-half of the students taking aeronautical courses. The Vancouver Branch has arranged to supply films to the CSC Student Section and two members of the Vancouver Branch have been invited to attend their next meeting at Royal Roads to review the role of CAI and to discuss the student program and the arrangements of a competition for the CAI Branch Student Award.

Mr. A. G. Reddy, Program Chairman, reviewed the proposed program for 1960-61. The program to the end of the year is firm and includes what should be an interesting speech by Mr. L. W. Olson of United Airlines on the subject, "Maintenance Operational Experience with the DC-8"; our usually well-attended and enjoyed "Fall Ball" and "Ladies Night" with the speaker, Hon. P. Gaglardi, Minister of Highways, B.C., speaking on the subject "Future of Aviation in B.C." The remainder of the year's program is more or less definite as planned and will include a panel discussion, the joint CAI/SAE meeting, a CAI tour speaker, our Annual General Meeting and dance, and the "Spring Wind-up" which will be a combined golf, fishing and dinner at Horseshoe Bay and Gleneagles Golf Course.

The night's program consisted of three very interesting and educational films produced by Shell Oil entitled: "Approaching the Speed of Sound", "Flying at the Speed of Sound" and "Supersonic Flight".

MEMBERS

NEWS

W. K. Ebel, F.C.A.I., formerly Vice-President, Engineering, of Canadair Limited has been appointed to the position of Staff Executive in the Washington office of Canadair's parent company, General Dynamics Corp., to assist the corporation's Vice-President for Engineering.

E. H. Higgins, F.C.A.I., formerly Chief Engineer, Aircraft, of Canadair Limited has been appointed Vice-President, Engineering.

J. A. Nicas, A.F.C.A.I., has been appointed Senior Regional Representative of the Dept. of Defence Production at Canadair Ltd.

H. H. Whiteman, A.F.C.A.I., has recently been appointed Anti-Submarine Warfare (ASW) co-ordinator and Chairman of the ASW committee which has been organized by Canadair Ltd.

T. G. Dunkin, M.C.A.I., has taken the position of Assistant Manager of the Sales Engineering Department at Canadair Ltd.

K. M. Molson, M.C.A.I., has been appointed Curator of the National Aviation Museum, Ottawa.

G. E. A. Thomann, M.C.A.I., formerly with Engineering Research Associates in Toronto has joined the Aero-Space Division, Boeing Airplane Co., in Seattle, Washington, as Research Specialist.

D. R. Hennig, Technical Member, has been engaged as Research Technician by the National Aeronautical Establishment in Ottawa.

J. P. Mentink, Technical Member, has recently taken a new position with Bausch & Lomb, Inc., Rochester, N.Y., as a Senior Mechanical Engineer.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 24th August, 1960, the following were admitted to the grades shown.

Associate Fellow

R. S. Swanson, Engineering Consultant, 4641 Hayvenhurst Ave., Encino, California.

Prof. H. J. T. Young (on transfer from Member)

Member

M. T. Corben, Area Representative, Smiths Aircraft Instruments Ltd., Kelvin House, Wembley Park Drive, Wembley, Middlesex, England.

W. Harding, Investigating Engineer, Service Dept., Canadair Ltd., P.O. Box 6087, Montreal, P.Q.

S. Sandell (on transfer from Technical Member)

Technical Member

P. J. Brennan, Technical Officer, National Aeronautical Establishment, National Research Council, Ottawa, Ont.: *3772 Albion Rd., Gloucester P.O., Ottawa, Ont.*

F. R. Brown, Instrument Technician, Fairey Aviation Co. of Canada, P.O. Box 69, Dartmouth, N.S.: *24 A Settle St., Dartmouth, N.S.*

C. Cantin, Inspector, Civil Aviation, Department of Transport, Hangar 4C, Montreal Airport, Dorval, P.Q.

H. I. Daffin, Service Representative, Rolls-Royce of Canada Ltd., Box 1400, St. Laurent, Montreal 9, P.Q.

J. R. M. Gordon, Lecturer, Department of Mechanical Engineering, Royal Military College, Kingston, Ont.: *132 Earl St., Apt. 3, Kingston, Ont.*

C. Robillard, Tool Planner, Canadair Ltd., Montreal, P.Q.: *7587 Francois-Chartrand St., Duvernay, P.Q.*

Associate

F. A. Drury, Management Development Assistant, Canadian Pacific Air Lines, Vancouver, B.C.: *4380 Erwin Dr., West Vancouver, B.C.*

M. J. Hart, Section Head, Service Dept., Canadiar Ltd., Montreal, P.Q.: *1586 Ducharme Ave., Outremont 8, P.Q.*

W. A. Mosher, Supervisor, Military Aircraft Sales, Canadair Ltd., P.O. Box 6087, Montreal, P.Q.

* * *

ADMISSIONS

At a meeting of the Admissions Committee, held on the 7th September, 1960, the following were admitted to the grades shown.

Associate Fellow

K. J. Radford, Director of Systems Evaluation, Air Force Headquarters, Ottawa, Ont.

Member

J. K. Andrews, Group Leader, Engineering, Canadair Ltd., Montreal, P.Q.: *344 Constantin, St. Eustache, P.Q.*

D. A. Clunis (on transfer from Technical Member)

A. Klein (on transfer from Technical Member)

W. E. Laundry (on transfer from Technical Member)

F/L J. G. McKenna (on transfer from Technical Member)

J. B. Phillips (on transfer from Technical Member)

O. R. Phillips, Senior Inspector, Aircraft, Canadian Pacific Airlines (Repairs) Ltd., Calgary, Alta.: *1627 - 19th Ave. S.W., No. 6, Calgary, Alta.*

F/L L. B. Pollock, RCAF, Test Pilot, Canadair Ltd., Montreal, P.Q.: *1460 Allan Ave., St. Martin, P.Q.*

Technical Member

F/O D. H. Allatt (on transfer from Student)

A. R. Baker, Engineer C, Canadair Ltd., Montreal, P.Q.: *4 Maple Ave., Ste. Anne de Bellevue, P.Q.*

T. E. Ervine, Service Engineer, Aero Service Dept., Rolls-Royce of Canada Ltd., Box 1400, St. Laurent, Montreal 9, P.Q.

D. R. Hennig (on transfer from Junior Member)

F/O G. W. Hosang (on transfer from Student)

S. Molder (on transfer from Student)

F/O M. D. Thom (on transfer from Student)

F/O K. V. Ujimoto (on transfer from Student)

Associate

K. D. Olson (on transfer from Student)

BOOKS

REVIEWS

Fundamentals of Rocket Propulsion. By R. E. Wiech, Jr., and R. F. Strauss. Reinhold Publishing Corp., New York, 1960. 135 pages. Illus. $5.50.

The foreword of this book indicates that it is a primer in rocket technology designed for those with a limited background in the true and stricter scientific disciplines. In its attempt to simplify "difficult" concepts such as mass, weight, acceleration, velocity and distance, it confuses itself by trying to be elementary in its approach. It would have been far better to have educated the reader in the methods of deriving fundamental scientific and mathematical principles than to perpetrate scientific half truths.

If the theoretical treatment is weak one might have expected greater consideration to be given to the engineering aspects but this is not the case. In general the line diagrams are not put together too well and often the explanatory text is not explicit. Thus in the chapter on liquid engines the function of solenoid control valves in relation to the main pneumatic flow valves is far from clear.

Just who will benefit most from this work is not too apparent; on the jacket it is suggested that, amongst others, possible candidates are "propellant chemists, chemical and mechanical engineers . . ." It is to be hoped that the technical capability of these groups has been grossly underestimated or progress in the field will indeed be slow!

This book is the first of a series. Perhaps some thought will in future be given to providing a more adequate treatment of basic scientific principles and, possibly for those readers with limited knowledge and time, more selective lists of recommended supplementary reading will be provided.

L. A. Dickinson

Aero-Thermodynamics and Flow in Turbomachines. By M. H. Vavra. John Wiley and Sons, Inc., New York, 1960. 609 pages. Illus. $14.50.

This book deals exclusively with the aerodynamic design of turbomachinery. It is primarily concerned with flow conditions at the design point and does not attempt to examine the problems of performance prediction or stage performance analysis, which are major studies in themselves. Consequently, this book will be of most value to those whose specific interest is the aerodynamic design of turbomachinery. Its purpose is to provide an understanding of the flow phenomena in turbomachines and to supply rational methods of formulating them mathematically. Vector and tensor analyses are used for this purpose and a knowledge of these techniques, or a willingness to acquire it, is essential if this book is to be used effectively.

The book is divided into three parts plus an appendix.

Part I sets up the fundamental relations for the analysis of arbitrary flows. An attempt is made to demonstrate the physical significance of the various aerodynamic concepts and to explain where and why simplifying assumptions or hypotheses are necessary to formulate the different laws. Because of its fundamental character, Part I of the book can serve as a basis for the analysis of fluid flows in fields other than that of turbomachines.

Part II treats flows of more special character or flows which are idealized either with respect to the properties of the fluids or the thermodynamic process they undergo. Efforts are made to demonstrate the different behaviour of absolute and relative flows and to show that the particular boundary conditions in turbomachines produce phenomena that usually do not exist in external fluid mechanics.

Part III is directly concerned with flows in turbomachines including the analysis of the flow in axial compressors and turbines. The appendix contains a useful review of vector analysis, treating material that is either used directly in the book or is considered to be helpful to readers with a limited knowledge of vector analysis.

It is obvious that this book will have greatest appeal for the applied mathematician. However the author does display a keen understanding of the physical aspects of turbomachinery flow problems and a large portion of the book, particularly in Part III, could be read with benefit by anyone interested in the aerodynamics of turbomachines. I suspect however that there are not too many people with this specific interest and background in this country to warrant a large sale.

S. L. Britton

Magnesium and Its Alloys. By C. S. Roberts, John Wiley & Sons Inc., 1960. 230 pages. Illus. $9.00.

Many of the scientific and technical books which are published today style themselves as "reference books of broad scope" and they include a not inconsiderable bibliography of references with which to support their claims. It is not every reader who has access to the references which are quoted and who must, of necessity, derive his knowledge from the information he can obtain from just such works as "Magnesium and Its Alloys".

This book, whilst being somewhat modest in size, undoubtedly packs between its covers an array of facts which would do credit to a much larger volume. Its composition is quite subtle in that the first quarter is largely theoretical in its approach and deals almost exclusively with Metal Physics. The second quarter begins to let its hair down a little and introduces some of the practical considerations which are of interest. For instance, twenty-seven constitutional diagrams, dealing with the binary alloys are presented, along with brief supplementary comments thereon. The author has the honesty to point out that only eight of these systems have any practical or commercial significance.

The last half of the book deals almost entirely with the cast and wrought alloys and the technologies involved in their processing; the chemical properties and finally the extraction and refining of the basic metal are well handled.

In slightly greater detail, the chapter dealing with "deformation" presents an explanation of the phenomenon which has bothered aircraft engineers for so long; namely, the fact that landing wheels seem to be able to absorb some terrific impacts without breaking, yet the ductility of the cast alloys is usually so low.

The progression from the older and better known Magnesium-Aluminum-Zinc ternary alloys to the modern somewhat sophisticated families of those containing Zirconium and Thorium makes interesting reading and shows how this Cinderella of the light metals can, and will continue to show some very interesting and advantageous properties especially in the field of Missilery.

After reading the chapter on chemical properties and the application of Magnesium anodes in their anti-corrosion capacity, it would not be surprising if a number of engineers were to be seen busily engaged on a "do-it-yourself" campaign to fix up their domestic water heaters in the approved manner.

Altogether, this little book will prove to be a useful and informative addition to the shelves of the library of those engineers and metallurgists who have regular dealings with Magnesium and its alloys, also to those who would only like to be a little better informed.

R. SMALLMAN-TEW

MAN-POWERED FLIGHT LIBRARY

The Institute has established a small library concerned with Man-Powered Flight. The first list of acquisitions appears below. Books and papers are available on loan to members of the Institute and members wishing to borrow them should address their requests to the Secretary, indicating how long they are likely to need them.

The Man-Powered Aircraft — A Design Study — NONWEILER, T. R. F., J. OF THE RAeS, VOL. 62, NO. 574, OCTOBER, 1958.

An appreciation is made of recent experimental and project work of relevance to the design of a very light weight aircraft capable of being taken off and flown by two men. The emphasis is on the aerodynamic problems involved. It is concluded that, although there are many difficulties still needing attention, all the information supports previous assertions that flight by muscular power alone is possible. The merits and demerits of a particular projected design are studied, and its performance and stability assessed.

The Katzmayr Effect and the Solution to Muscle Powered Flight — TRANSLATION BY RICHARD, G. C., LES AILES, 27 SEPTEMBER, 1958.

A summary of the Katzmayr effect, reference to tests and suggestions for its development and application.

Man-Powered Aircraft Prototypes — SHENSTONE, B. S., THE AEROPLANE AND ASTRONAUTICS, 30 OCTOBER, 1959.

Brief description of Hartman's ornithopter using a spring-balanced wing to be flapped at natural frequency and Perkins' inflated wing machine.

Performance Measurements of a Soaring Bird — RASPET, A., AERO. ENGINEERING REVIEW, VOL. 9, NO. 12, DECEMBER, 1950.

In order to understand dynamic soaring, the author describes his method of collecting data from a sailplane, observing buzzards, and explains the bird's method of obtaining lift and reducing drag by use of the tip feathers.

Some Notes on Man-Powered Flapping Wings — RENDEL, D.

Brief analysis of obtaining lift with flapping wings. Describes construction and geometrical characteristics of vehicle, in particular the wings, and has three drawings.

A Sport of the Future, Man Powered Flight — IRVING, H. B.

Relates establishment of Man Powered Flight Group of RAeS. Reviews briefly power required for lift and flight, Nonweiler's tandem, takeoff assistance (with College of Aeronautics recommendation) and Germany's efforts in the 1930's.

Prospects for Skycycles—AERONAUTICS, FEBRUARY, 1959.

Precis of "Man Powered Flight" by B. S. Shenstone; fourth Henson and Stringfellow Lecture (RAeS Yoevil). Covers briefly Haessler-Villinger and Bossi-Bonomi, reviews the structural, aerodynamic and power problems and some suggested solutions, recommends development of fixed wing configuration and discusses definition of "Flight".

Flying Bicycle — NEWSWEEK, 6 JULY, 1953.

Popular science style account of Dr. A. Raspet's work on a flying bicycle, explaining boundary layer control and propeller pump.

The Aerodynamics of Soaring Bird Flight — VINOGRADOV, I. N., DOSART, MOSCOW, 1951, TRANSLATED BY TOMS, B., RAE LIBRARY TRANSLATION NO. 846.

This book discusses the structure and basic muscular mechanism of birds and shows how they achieve flight. It includes reports of tests and measurements made on living and model birds. The two main points emphasized are firstly the method of boundary layer control achieved by the arrangement of the feathers in a bird(s) wing and secondly the complex deflections of the wing involved in producing thrust and maintaining stability and control. Where possible, mathematical analysis of the phenomena is given and test apparatus and measurements are described in considerable detail. The book concludes that the use of the flapping wing mechanism provides an opportunity of achieving a much more efficient flight regime and that a study of this form of flight could lead to great improvements in flying machines generally. The question of muscular flight by man is briefly considered and it is concluded that using ornithological flight techniques it should be possible to achieve human flight with muscle power.

Unusual Aerodynamics — SHENSTONE, B. S., CAI LOG, VOL. 1, NO. 4, DECEMBER, 1954.

Some considerations of hairs on insect wings, boundary layer control of birds and dolphins, flapping wings, kites and sails, and a brief challenge to man-powered flight.

Correspondence — WHILLANS, M. G., AND HOCKING, B., CAN. AERONAUTICAL JOURNAL, VOL. 5, NO. 7, SEPTEMBER, 1959.

Considerations of insect flight, hairs on wings, the haltere principle, streamlining.

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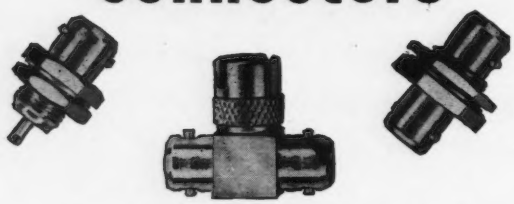

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HYPERSONIC FLOW

11th Symposium of the Colston Research Society, University of Bristol, 1959. Edited by Professor A. R. COLLAR and Dr. J. TINKLER.

$13.50 delivered

This book offers something to all those interested in the subject of hypersonics, whether they are already actively engaged in it, or whether they wish to extend their knowledge of subsonic and supersonic aerodynamics to include the special characteristics of flow at very high speeds.

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(It is regretted that in the recently issued List of Members 1960 the price of this book was incorrectly stated – Ed.)

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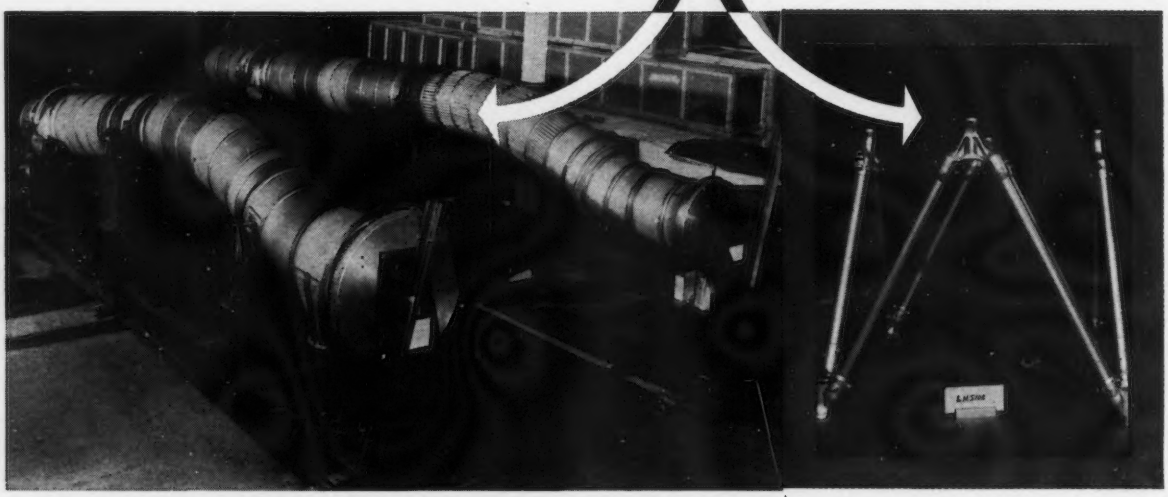

Engine mountings and jet tail pipes installed in Canadian-built Canadair CL-44 aircraft for the R.C.A.F. are produced by the Manufacturing Division of Bristol Aero-Industries' extensive Winnipeg plant. The CL-44 is a derivative of the world-famous Bristol Britannia now in service with major air lines. The jet tail pipes and muffs are made principally of stainless steel and titanium sheet, coupled by Marman flanges.

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